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ABSTRACT

This manual on hydraulics is one of a series of individualized instructional materials for students. The manual is self-paced, but is designed to be used under the supervision of an instructor. The manual contains 10 assignments, each with all the information needed, a list of objectives that should be met, and exercise questions that can help in meeting those objectives. The assignments cover the following topics: using the manual, introduction, liquid flow, pressure gauges and volume meters, hydraulic pumps, hydraulic valves, hydraulic cylinders, hydraulic motors, hydraulic accumulators, and hydraulic liquids. Assignments are illustrated with line drawings. (KC)

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Introduction to Hydraulics

Student's Manual

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Foreword

This publication is one of a series of individualized instructional materials. Students using this material can work at their own pace, enabling them to concentrate on areas that best fit specific needs. The design of the instruction makes it possible to relate work experience with materials studied at school.

Although the material is designed for individualized study, it should be used under the supervision of an instructor. For that reason, two basic publications are offered—a student's manual and an instructor's guide.

The *student's manual* is for the use of the person in training. The assignments in the manual are self-contained. Each assignment has the information needed, a list of objectives that should be met, and exercise questions that can help the student meet those objectives.

The *instructor's guide* has additional information that may help the instructor help the student. There are suggestions on how the student should use the student's manual and how the instructor can coordinate work experience and classroom study. The instructor's guide also contains (1) answers to exercise questions and assignment test questions, (2) one set of assignment test questions, and (3) a work sheet that the instructor can use to relate instruction to job experience for the student.

Although both publications are copyrighted, an instructor should feel free to reproduce copies of the assignment tests and work sheet. If the instructor prefers, copies of these same sheets can be ordered separately for individual students from Extension Instruction and Materials Center, The University of Texas at Austin, P.O. Box 7218, Austin, Texas 78712.

Jack E. Robertson, Ph.D.
Director, Extension Instruction
and Materials Center

A Special Note to the Student

The assignments in this manual are designed to help you learn. You will gain more from this material if you know how to work the assignments. For that reason, Assignment 1, which is about how to use this manual, should be completed first.

Objectives: After completing this assignment, you will be able to—

1. list the four parts of each assignment;
2. state the purpose of the objectives;
3. tell the proper sequence of study for each assignment; and
4. tell why the assignment test should be a snap.

1

How to Use This Manual

You, the student, might be surprised if you knew how closely your interest in this manual and that of the author compare. For instance, did you know that the author's first concern was to make learning as easy as possible? In fact, the organization of this manual has been based on how to make the information in each assignment easy to learn and yet stay in your mind. Each assignment has four parts: (1) the learning *objectives* for the assignment, (2) the *technical information*, (3) the *exercise*, and (4) the *assignment test*. When studied in this order, this arrangement should provide you with the greatest learning opportunity.

To illustrate, go back—right now—and reread the objectives. Had you really paid any attention to the objectives the first time you read them? Or did you even read them? They are important because they tell you what you should be able to remember after completing the assignment. You read the objectives so you will know the important information to look for. Then, as you read, things you need to know will pop into your mind. A short assignment test has been written for each assignment.

Be sure to read the objectives first, the technical information second, and then answer the questions in the exercise. This order has a purpose. First, you learn what to look for when reading. Then you read and learn the information needed to meet the objectives. Exercise questions then guide you for a third time over the facts considered important. This drill ingrains the information in your mind.

If you are in a co-op class, your notebook should show anyone what you have studied during the time you have been in the program. The following rules may be useful in answering the exercise questions. (Of course, if your instructor has certain rules, by all means follow them.)

1. All work should be done on regular two-, three-, or five-hole loose-leaf paper—never on spiral notebook paper.
2. Either (a) write the answers in complete sentences or (b) write the questions and then write only the answers on the line below.
3. VICA members are supposed to do their work in their own handwriting if it is to be entered in competition.
4. For your own benefit, include a correction sheet in your notebook. You can write down the correct answers after the exercises have been checked by your instructor.

A word of caution in working the exercises: *do not hurry through the questions*. Take your time and learn each assignment as you go. Your instructor is not interested in how many assignments you turn in. His or her main concern is *how much you have learned*. Just stay busy, do your work, and let the number of assignments turned in take care of itself.

If you study each assignment as instructed here, the fourth part—the test—will be a snap. That is because you will have covered the information three times before taking the test. The test is based on information stated in the objectives.

If you do not do well on the test, go back to the objectives, and study the assignment again. After reading the objectives and the technical information and completing the exercise, ask your instructor to retest your knowledge. If you still do not do well, perhaps the author should redo the assignment! This goes back to the statement that your interest in this manual is the same as that of the author. You see, if you fail to learn, the author, through this manual, has failed to teach.

Exercise

1. How does your interest in this manual and that of the author compare?
2. List the four parts of each assignment.
3. Why are the objectives important?
4. Of what secondary importance are the objectives?
5. Give the proper order or sequence of study for each assignment.
6. What is the purpose of studying the assignment in the proper order?
7. If your instructor is not particularly interested in the number of assignments you turn in, what is he or she concerned about?
8. Why should the short test be a snap?

2

Introduction

Objectives: After completing this assignment, you will be able to—

1. explain the basic principles of hydraulics;
2. name five advantages of hydraulic systems;
3. explain how force is multiplied; and
4. explain how the travel distance of the piston exerting the force is affected by the multiplication of force.

The word *hydraulics* is based on the Greek word for water. The term originally meant a study of the physical behavior of water at rest and in motion. However, its meaning has broadened to cover the physical behavior of all liquids, particularly oils in present-day hydraulic systems.

Liquids are used in hydraulic systems to transmit force from one point to another and to multiply force. There are several advantages to using liquids rather than some mechanical means.

1. The different parts of a hydraulic setup can be located at widely separated points. Forces can be carried up and down or around corners with small loss of efficiency and with no complicated mechanisms required.

2. Hydraulic systems are economical to operate. They have fewer moving parts and fewer points of wear, and they lubricate themselves.

3. Force can be multiplied through the selection of different sizes of cylinders and pistons.

4. Hydraulic systems are more compact than other systems. A hydraulic motor of a given horsepower is much smaller than a comparable electric or gasoline motor. A hydraulic press is much smaller than a comparable mechanical press.

5. Hydraulic systems are safer than mechanical systems since they do not have as many moving parts. Overloads are more easily controiled by relief valves.

Three basic principles are important to hydraulics:

1. *Liquids are shapeless.* While solids always have a definite shape, liquids conform to the shape of their containers. Since they do conform to any shape, they are easily piped almost anywhere by using gravity or by applying force to them.

2. *Liquids are incompressible.* In spite of having no shape of their own, liquids are even less compressible than most solids. In fact, when a force is applied to a confined liquid, the reaction is much the same as when force is applied to a solid. This is not to say that liquids are not compressible at all. They are only slightly compressible. In fact, if a cubic inch of water had a 15-pound force exerted on it, it would compress only by 1/20,000 of its volume. When the force is removed from a liquid, it returns to its former volume.

3. *Liquids transmit applied pressure equally in all directions* (fig. 1). Every square inch of the inside of a container, regardless of its shape, has an equal pressure exerted on it. This pressure is always exerted at right angles to the inside wall. The shape of the container does not alter the pressure exerted by the liquid.

Pressure is defined as *force divided by the area* over which the pressure is distributed. In figure 2, a 100-pound weight is placed on piston 1. This piston's face is 10 square inches. Therefore, it exerts 10

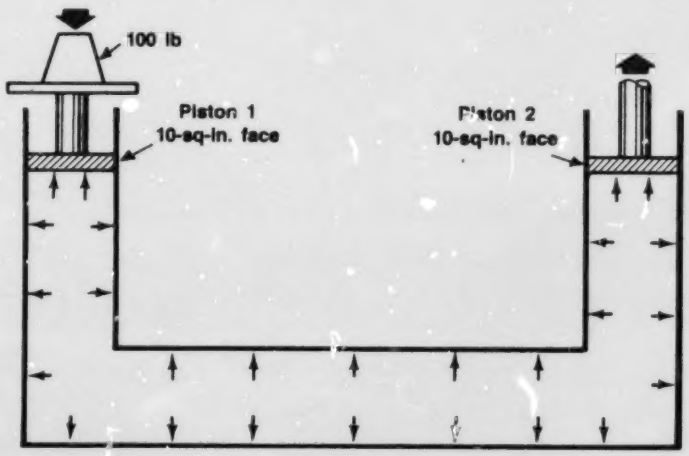

Fig. 1. Liquid transmits applied pressure equally in all directions.

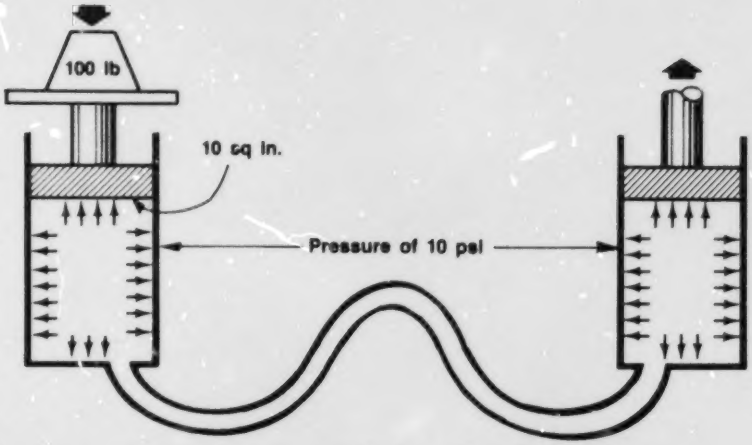

Fig. 2. Pressure equals force divided by area.

pounds of pressure per square inch on the liquid. This pressure is distributed equally throughout the entire system. Piston 2 also has 10 square inches on its face. This means that 100 pounds of force is exerted on the piston (force = pressure × area).

This points out an interesting fact about pressure and force. Although they are directly related, they are not one and the same. While the pressure in a system may remain constant, the force exerted by the pressure is proportional to the square inches of surface area upon which the pressure is exerted. This means that force may be multiplied. For instance, in figure 3, a 100-pound weight is applied to piston 1, which has 10 square inches on its face. This exerts a pressure of 10 pounds per square inch (psi) on the system. Piston 2 has 20 square inches on its face. This means that 10 psi is exerted on twice as many square inches on piston 2 as on piston 1. Therefore, 200 pounds of force is exerted on piston 2.

Multiplication of force is possible because of the difference in the areas of the pistons, usually called *differential areas*. Differential areas do not have to be on two different pistons. They can be, and sometimes are, on the same piston. Figure 4 shows a single piston in a cylinder having a piston rod attached to one side of the piston. Liquid under pressure is admitted to both ends of the cylinder equally through the pipes. The opposed faces of the piston behave as two pistons acting against each other. The area of one face is the full area of the cylinder (6 square inches), while the area of the other face is equal to the area of the cylinder minus the area of the piston rod (2 square inches). This leaves the effective area of 4 square inches on the right face of the piston. Obviously, the pressure on both sides of the piston will be the same, 20 psi. Using the formula to determine force, we multiply 20 times 6, which equals 120 pounds. Using the same

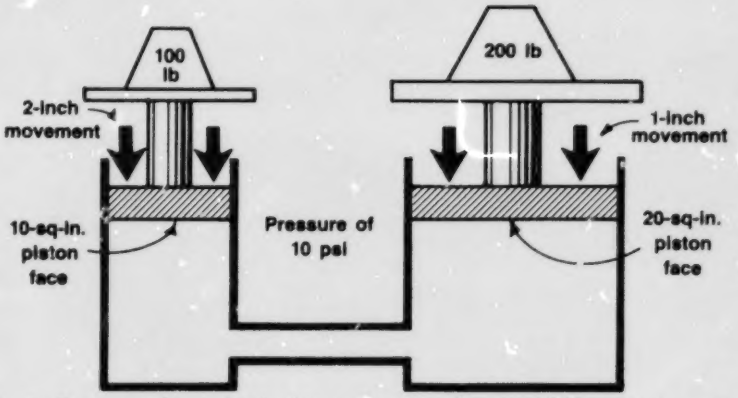

Fig. 3. Force can be multiplied by increasing the size of the receiving piston.

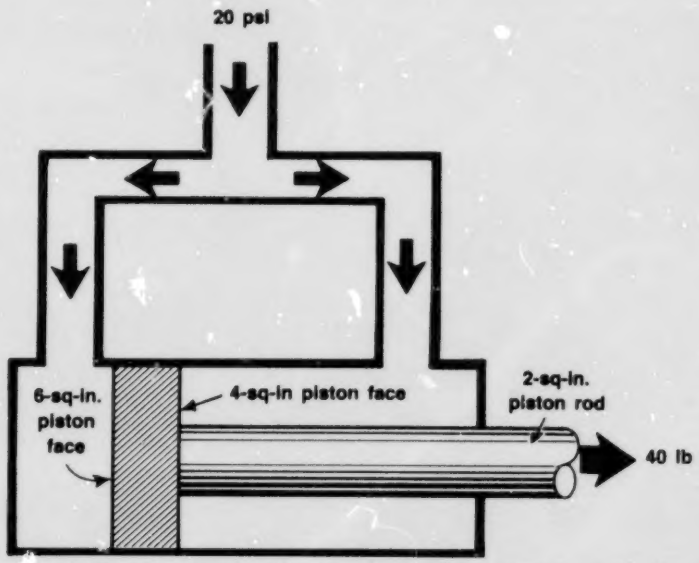

Fig. 4. Different areas on the two faces of one piston create force.

formula, the force on the right side is 80 pounds. There is a net unbalanced force of 40 pounds acting to the right. The piston will move in that direction.

One of the greatest advantages of the hydraulic system comes from the ability to multiply force by selecting the proper sizes of cylinders and pistons. However, when work is performed by hydraulics systems, another factor comes into play. This is the *length of movement* of the pistons when multiplying force. It first appears that we are gaining force without having to give up anything. However, we know this cannot happen. Again, look at figure 3. Piston 1 is exerting 100 pounds of force. It creates 10 psi on the hydraulic system. This 10 psi pressure exerts 200 pounds of force on piston 2. However, in order to move piston 2 one inch, piston 1 must travel 2 inches. This points out that when the force is multiplied by any given amount, the travel distance of the piston exerting the force must be multiplied by the same number. What this means is that the volume of the liquid *moved from* one cylinder must be exactly equal to the volume of liquid *moved into* the other cylinder.

Exercise

1. What is the present-day meaning of the word *hydraulics*?
2. What are liquids in hydraulic systems used for?
3. Name five advantages of hydraulic systems.
4. How do liquids get their shape?
5. How does the compressibility of liquids compare with the compressibility of most solids?
6. How is the pressure of a liquid distributed inside a container?
7. What is the formula for determining the pressure of a liquid?
8. How is force multiplied when using hydraulics?
9. How is the distance a piston must move affected by the multiplication of force?
10. How does the volume of liquid moved from one cylinder compare to the volume of liquid moved into the other cylinder?

Objectives: After completing this assignment, you will be able to—
1. define the terms related to liquid flow;
2. describe factors that affect liquid flow; and
3. explain the functions of the parts of a hydraulic system.

3

Liquid Flow

Liquid flow has several elementary characteristics: volume and velocity, steady and unsteady flow, even and turbulent flow, and force and inertia changes that occur in the flow.

Volume is the quantity of liquid that will pass a given point in a hydraulic system in a given unit of time. Volume of flow can be stated in a number of ways. For example, it can be stated in cubic feet per minute, gallons per minute or per hour, etc. Gallons per minute is the most commonly used method of stating volume in the United States.

Velocity is the rate or speed at which the liquid is moving past a particular point in the system. Like volume, it can be stated in several ways, but is normally stated in feet per second. Volume and velocity are often considered together because they are interrelated. In other words, if the volume remains constant, the velocity will remain constant. The velocity will change only if the size of the conduit changes. The velocity will decrease if the conduit becomes larger and will increase if the conduit becomes smaller.

Liquid flow may be steady or unsteady. A *steady flow* is one in which the liquid flows at a constant rate. An *unsteady flow* is one in which the flow rate changes from moment to moment.

Even flow and turbulent flow affect the velocity at which the liquid can flow. An *even flow* is one in which the liquid flows in a straight line without rolling and tumbling in swirls and eddies as it moves through the conduit. Liquids flowing at low velocities generally have an even flow. A *turbulent flow* is one in which the liquid does not flow evenly but has swirls, eddies, and

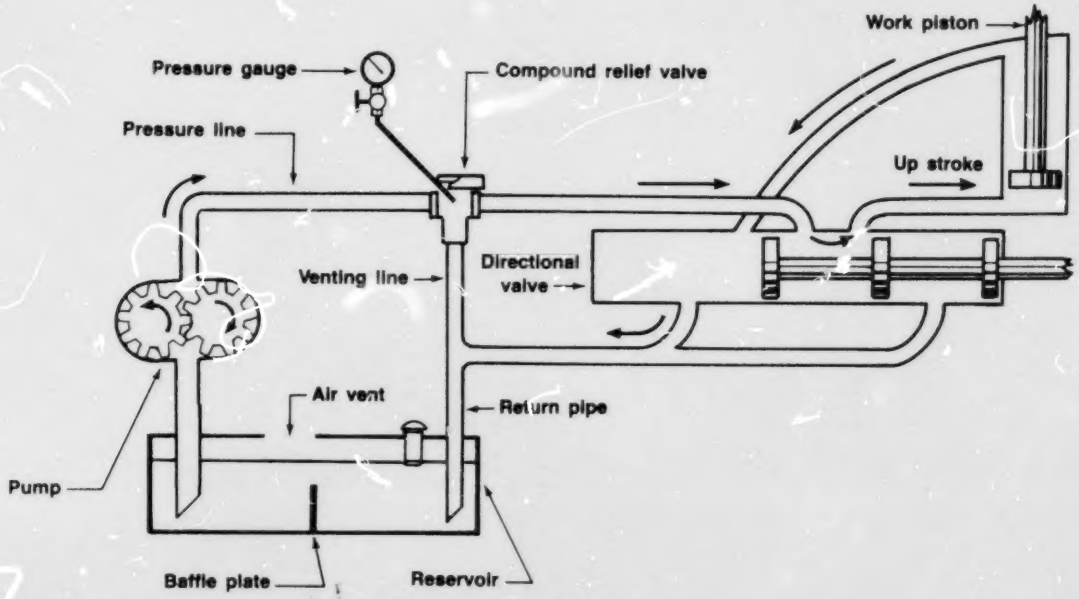

Fig 1. Basic parts of a hydraulic system

cross motions as it flows through the conduit. Turbulent flow develops friction and thus slows the flow of the liquid.

Turbulent flow is caused by a high velocity of the liquid and by obstructions in the pipe. These obstructions can be curvature of bends, roughness of the pipe, or the number of bends in the pipe. Pipe manufacturers design pipe that will offer the least resistance to flow and cause the least turbulence. In order to prevent turbulence, the pipe should be clean and smooth on the inside and should have as few bends as possible. The pipe should be bent on a radius of not less than 2 1/2 to 3 times the inside diameter of the pipe. With even flow, losses due to friction increase directly with the velocity. With turbulent flow, losses due to friction increase much more rapidly.

Two other factors affect the motion of all matter—inertia and force. *Inertia* means the tendency of any object (or mass) to resist being set in motion if it is at rest or to resist any change in its rate of motion or direction of motion if it is already in motion. Stated another way, if a mass is in a state of rest, it tends to remain at rest. If it is in motion, it tends to continue in motion with the same velocity and in the same direction. In order to overcome this tendency to resist change in state of rest or motion, a *force* must be employed. There is a direct relationship between the amount of force exerted and the inertia of the mass it acts against. The amount of force required in a hydraulic system depends on two factors—the mass of the liquid and the work to be done.

The following is a description of the basic parts of a hydraulic system (fig. 1) and how liquid flow is used to do work.

First, a *reservoir* stores the liquid not being used at the moment to do work. As the system does more work (moves the piston further), more liquid is removed from the reservoir and pumped through the system.

Second, a *piping system* routes the liquid to the various parts of the system.

Third, a *pump* pumps the liquid to do the work.

Fourth, an *energy source* is required. This can be in the form of a person using a hydraulic jack, or it can be an electric motor or a reciprocating engine in larger hydraulic systems. In any event, the energy source must be able to produce enough energy to overcome gravity, inertia, and friction and still do the work required.

Fifth, *valves* are required to direct the liquid to the proper pipe and working parts.

Sixth, some *mechanism for doing work* is required. This can be a cylinder and piston, a hydraulic motor, or other mechanism specifically designed to do work.

Exercise

1. Define *volume*, as related to liquid flow.
2. How is volume most commonly expressed?
3. Define *velocity*.
4. How is velocity commonly expressed?
5. Why are velocity and volume often considered together?
6. What is *steady flow*?
7. What is *even flow*?
8. What is *turbulent flow*?
9. What kind of obstructions can cause turbulent flow?
10. What is the sharpest curve recommended in pipe?
11. What is *inertia*?
12. What factors affect the amount of force required in a hydraulic system?
13. What factors must an energy source overcome before being able to do work?
14. What function do the valves serve?

4

Pressure Gauges and Volume Meters

Objectives: After completing this assignment, you will be able to—
1. explain the importance of the shape of a Bourdon element;
2. explain how a Bourdon tube works;
3. describe the advantages of the Bourdon elements; and
4. explain how a nutating piston meter works.

Pressure gauges are used in hydraulic systems to measure system pressures so that the operator can maintain efficient and safe operating pressures.

Bourdon gauges use elements that are made in a "C," spiral, or helical shape (fig. 1). One end of the element is stationary, and the other is free to move. As pressure builds up inside the element, it attempts to straighten out. If the elastic limit of the element is not reached, the element will return to its original position when the pressure is released. The free end motion, or "tip travel," is directly proportional to the amount of pressure inside the element.

The *C-tube* is the most commonly used Bourdon element. It is easier to manufacture in uniform quality and large quantity. It also occupies less space in both depth and width than the spiral and helical units.

The advantage of the spiral and helical units is that they provide much greater movement, or tip travel. In many instances, the smaller motion of the C-tube is increased by using gears or levers (fig. 1). C-tubes are stable and rugged. They can flex about the set point indefinitely, yet adjust to pressure changes with microscopic accuracy. Spiral and helical Bourdon tubes provide greater tip travel for a given pressure. This permits the indicator hand or pen arm to be attached directly to the free end of the tube (see fig. 1). Another advantage these tubes have over the C-tube is that greater accuracy is obtained through the direct connection than is possible through levers and gears. There is less lost motion and friction to interfere with accurate gauging of pressures.

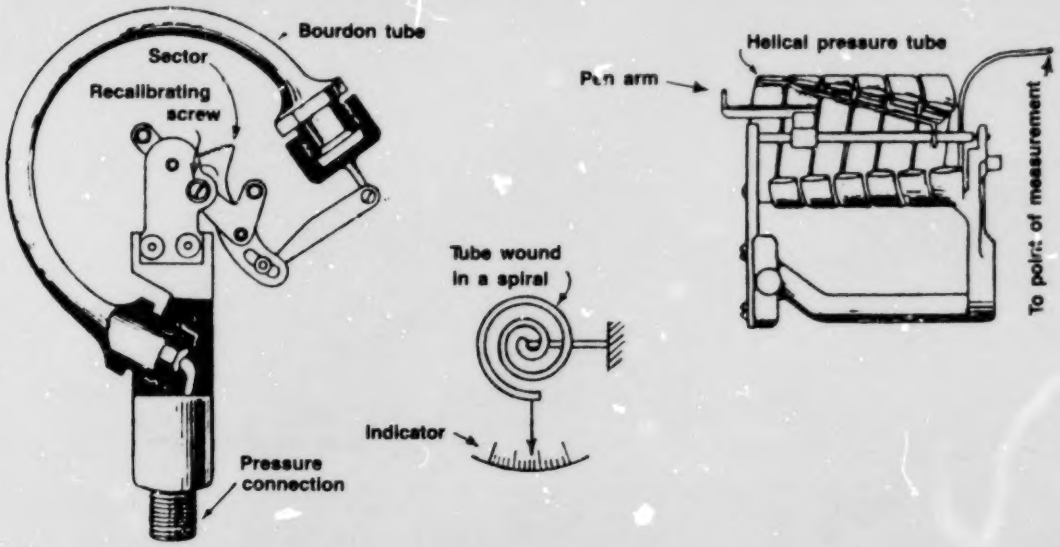

Fig. 1. Three basic types of Bourdon tubes or elements

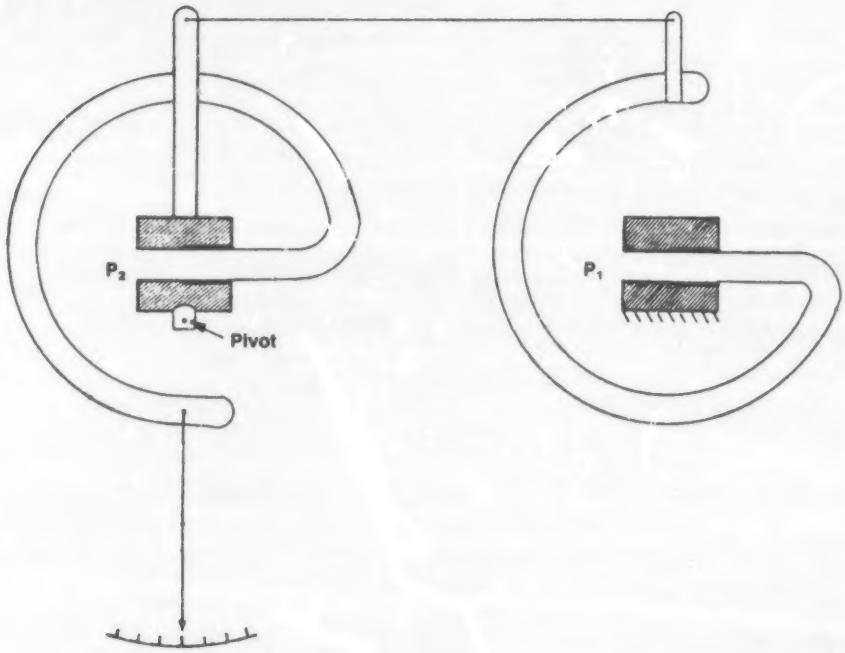

Fig. 2. Bourdon tubes arranged to measure differential pressure

Bourdon tubes can be used to measure the difference between two pressures. The differential pressure is measured by connecting two Bourdon tubes that receive pressure from two different sources. In figure 2, the first tube (on the right) is mounted in an upright position, and the second tube is mounted 180° from the first tube. The pressures cause the two tubes to pull against each other. The stationary end of the second tube is mounted on a pivot with a lever connected to the traveling tip of the first tube. The traveling tip of the second tube has an indicator hand that registers the difference between the pressures of the two Bourdon tubes.

Volume meters are displacement meters that use the energy from the flowing liquid to operate the indicating mechanism. The following describes the operation of a *nutating piston meter.* In operation, liquid passes through a fixed volume measuring chamber divided into upper and lower compartments by a piston that resembles a disk. As one compartment is being filled, the other compartment is being emptied. As the liquid passes through the compartments, it causes the disk to roll around in the chamber.

As shown in figure 3, the piston is limited in its motion by (1) a ball-like center section that rides in a socket and prevents vertical motion of the piston, (2) a disk that contains a single deep and narrow slot into which a rigid separator plate fits that prevents free motion, and (3) a pin that protrudes from the ball and rides against a fixed conical surface to force the disk to assume a cocked position at all times.

Look at the bottom left-hand drawing in figure 4. At this position

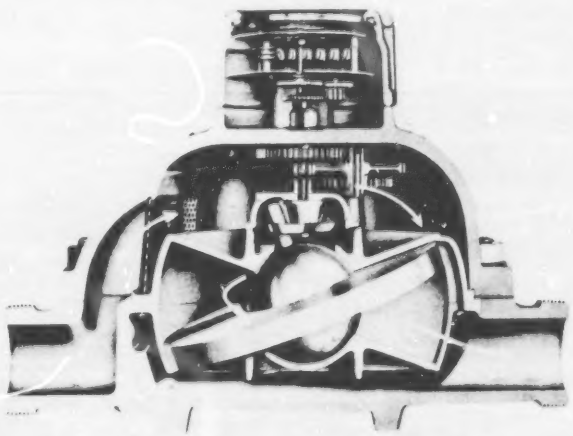

Fig. 3. Nutating piston positive-displacement meter. (Courtesy American Motor Controls, Inc.)

of the disk, liquid from a previous cycle is trapped *under* the right side of the disk and only goes out the discharge port on the right side of the rigid separator. Liquid from upstream entering the inlet port (left side of the rigid separator) flows under the disk and tends to lift it. The disk responds to this lifting force by squeezing liquid out through the discharge.

At the upper left-hand drawing in figure 4, you can see that liquid is also flowing *above* the disk. As you move to the upper center drawing, it is clear that most of the liquid trapped from the previous cycle has now been forced out into the downstream. Also, you can see, in the upper right-hand drawing, that another quantity of liquid is about to be trapped below the disk. Liquid is now free to travel in the cavity *above* the disk and begin a new cycle.

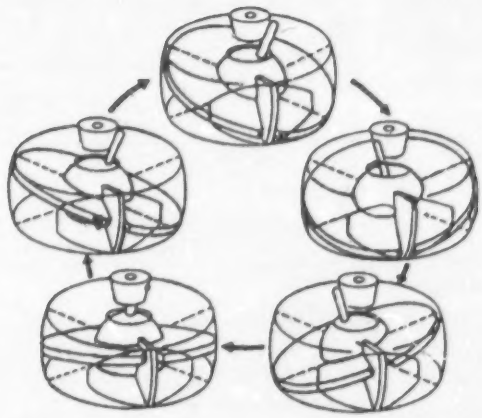

Fig. 4. Operation of the nutating disk

Exercise

1. What is the importance of the shape of a Bourdon element?
2. How is tip travel related to the pressure inside the element?
3. Why is the C-tube the most commonly used Bourdon element?
4. What is the advantage of the spiral and helical units?
5. How can the motion of the C-tube be increased?
6. Why are the spiral and helical tubes with the direct connections more accurate than C-tubes with levers or gears?
7. How are two Bourdon tubes arranged so that they can measure the difference between two pressures?
8. What powers a nutating piston meter?
9. What are the three major parts of a nutating piston meter?
10. Where does the liquid flow through the nutating meter?

5

Hydraulic Pumps

Objectives: After completing this assignment, you will be able to—
1. explain the purpose served by pumps and
2. explain the principle upon which each of the pumps operate.

A *pump* is a device through which an external force can be transferred to a liquid. The liquid is forced, under pressure, through a hydraulic system to some point at which it will do work. The pump develops no power of its own. It simply transfers power from one source to another

Classifications of Pumps

All pumps are classified either as a positive-displacement pump or as a non-positive-displacement pump. A positive-displacement pump is one such as the reciprocating pump shown in figure 1. Liquid is drawn into a chamber, and a seal prevents it from going back. Force is applied to the chamber, and the liquid is forced into a sealed hydraulic system. Again, a seal prevents the liquid from returning to the chamber. One characteristic of a positive-displacement pump is that if the flow of the liquid is stopped while the force continues, the pump will be destroyed since the liquid cannot be compressed.

A **non-positive-displacement pump** is one such as that shown in figure 2. The liquid is drawn into a chamber into which an impeller is rotating. The impeller deflects the liquid into the hydraulic system. However, there is no seal to prevent the liquid from returning to the chamber. Only the force of more liquid being deflected into the hydraulic system prevents the liquid from returning. If something prevents the liquid from flowing through the hydraulic system, the pressure in the system will soon equal the force of the deflecting

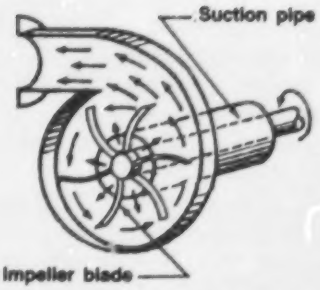

Fig. 2. Non-positive-displacement pump (impeller type)

liquid. When this happens, liquid is no longer pumped, but merely rotates with the impellers. However, the pump is not destroyed since the liquid is deflected rather than compressed.

Pumps are also classified according to the type of device used to pump the liquid.

Reciprocating pumps (see fig. 1) receive their name from the fact that the piston that applies the force moves *back and forth*, drawing the liquid into the cylinder and then forcing it out. Atmospheric pressure forces the liquid into the cylinder as the piston moves backwards. A check valve lifts up to allow the liquid to enter from the reservoir. Another check valve remains closed to prevent liquid in the hydraulic system from returning to the pump. As the piston begins to move back, the valve to the reservoir closes, preventing liquid from returning to the reservoir. The check valve to the

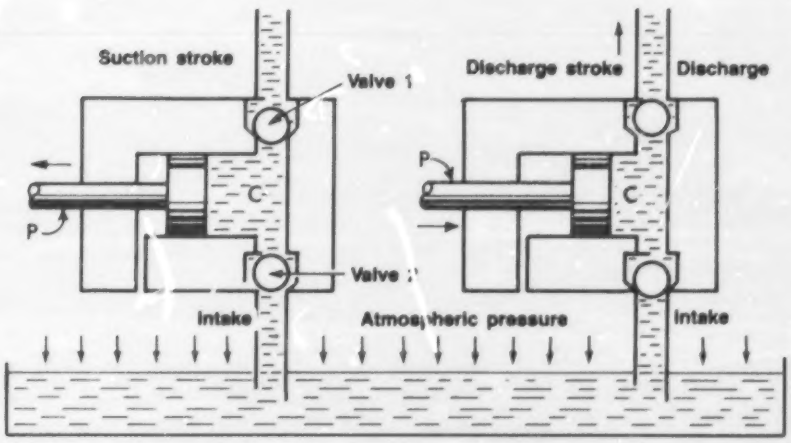

Fig. 1. Positive-displacement pump (piston type)

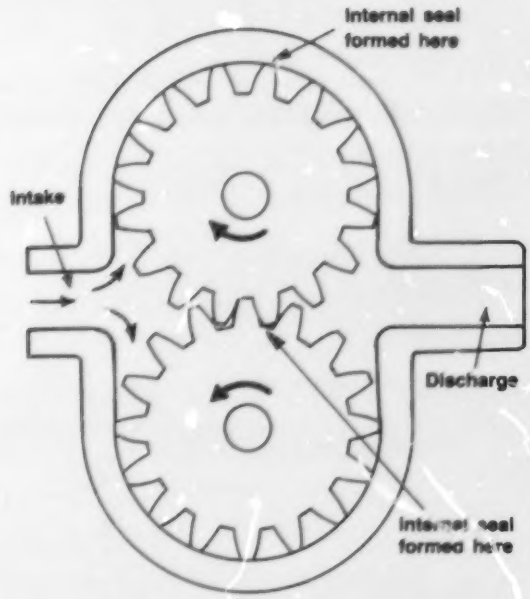

Fig. 3. External gear pump

hydraulic system opens to permit the liquid to enter the hydraulic system.

Rotary pumps use their rotary motion to carry the liquid from the reservoir to the hydraulic system. Types of rotary pumps are an external gear pump (fig. 3), an internal gear pump, a rotor-type pump, a lobe pump, or a rotating plunger pump. In spite of the different types, all rotary pumps operate on the same principle. A rotor is rotated in the pump chamber so that the liquid is carried or pushed from the intake side of the pump to the discharge side. Figure 3 illustrates this action in an external gear pump. Liquid is carried from the intake (suction) side to the discharge side in the spaces between the teeth of the gears as they rotate. Liquid is forced into the hydraulic system as the gears mesh, and the teeth occupy the space that the liquid had occupied.

Centrifugal pumps (fig. 4) are those that use the centrifugal force created by rotating the liquid. *Centrifugal force* is the tendency of any object to move away from the center when it is rotated. The faster the rotation, the greater the force on the object to move it away from the center. Liquid enters the pump at the center. It is given a rotary motion in the pump chamber by the rotation of the impeller blades. This rotating motion slings the fluid away from the center and into the throat of the discharge nozzle of the pump.

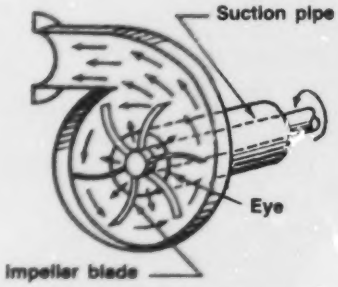

Fig. 4. Centrifugal pump

Types of Rotary Pumps

External gear pumps (see fig. 3) have two gears in mesh. These gears and the housing are closely machined so that the teeth form a seal with the housing. One gear drives the other.

In operation, a suction or vacuum is created when the teeth come *out* of mesh on the intake side. Atmospheric pressure forces liquid into the spaces between the teeth. Since the teeth and the housing form a seal, the liquid cannot leak back. As the teeth mesh again, the liquid is forced out the discharge side of the chamber.

Internal gear pumps (fig. 5) operate much the same as external gear pumps. However, one of the two gears is internal, meaning the teeth face the inside. The external gear operates inside the internal gear. Being inside the internal gear, the teeth of the two gears cannot form a seal with the housing surrounding them. A crescent is placed between the two gears. It is designed to fit

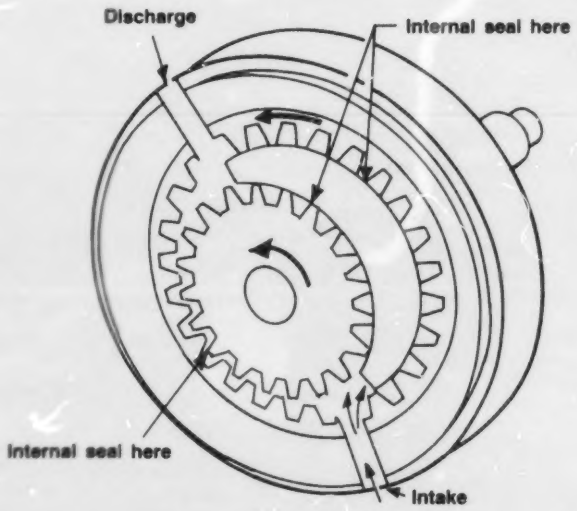

Fig. 5. Internal gear pump

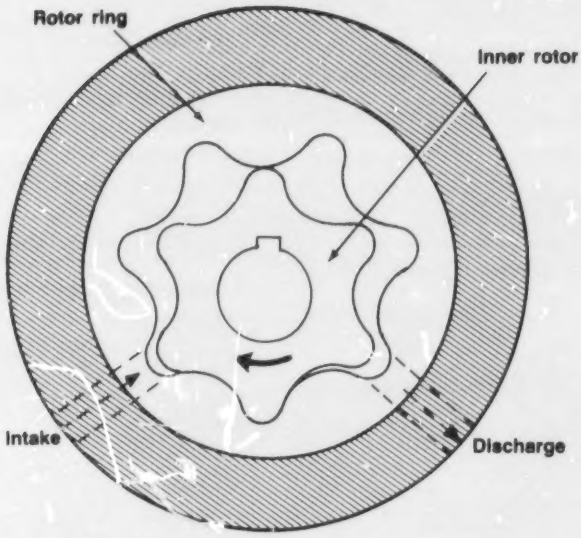

Fig. 6. Rotor pump

the arc formed by the two gears, and make a seal to prevent the liquid from returning to the intake side. In operation, the external gear is attached to the power source. It turns the internal gear with which it meshes. As the gears come out of mesh on the intake side, liquid is forced into the spaces between the teeth. As the teeth of the two gears rotate, a seal is formed by the crescent that separates the intake side from the discharge side. As the teeth come into mesh on the discharge side, the liquid is forced out into the hydraulic system.

Rotor pumps (fig. 6) are actually internal gear pumps that have rotors with a few large teeth called *lobes*. The lobes form a seal with each other. The inner rotor powers the outer rotor. Notice that the inner rotor has one less lobe than the outer rotor. Only one lobe of the inner rotor is in contact with the outer rotor. This causes the lobes of the inner rotor to slide over the lobes of the outer rotor, maintaining a seal at all times. This separates the intake side of the chamber from the discharge side.

Vane pumps (fig. 7) operate much like rotor pumps. In fact, they use the same principle, with the vanes serving the function of sealing the offset rotor against the housing. The vanes fit in slots in the rotor, which is offset and surrounded by a circular housing. Centrifugal force holds the vanes in contact with the housing. On the intake side of the chamber, liquid is drawn in as the rotor turns and the vanes extend further out from the center of the rotor. This increases the volume of the space between the vanes. The vanes begin to move back toward the center of the rotor after it has reached the midpoint of the chamber. As the chamber is reduced in size, liquid is forced out the discharge side and into the hydraulic system.

Axial piston pumps are those in which the cylinders and pistons operate parallel to the axis of the pump. They are reciprocating piston pumps. This means the piston moves back and forth to pump the liquid. However, instead of a crankshaft, a *swashplate* is used to provide the reciprocating motion. This is a plate that is tilted at an angle to the cylinder bore (fig. 8). Either of three methods may be used to provide the reciprocating action.

One method is to mount the swashplate in a fixed position (fig. 9). Notice that the pistons are connected directly to the swashplate. The swashplate rotates on the face of the swashplate yoke. The reciprocating action comes from rotating the cylinder block. This causes the pistons to rotate. As they rotate, they follow the fixed angle of the swashplate. Thus, at the top in figure 9, the piston is at the bottom of the cylinder. As the cylinder block continues to rotate, the piston moves toward the top of the cylinder. Continued rotation repeats the cycle. In order to increase efficiency and produce a more constant flow of liquid, a pump may have as many as ten cylinders in the block. Intake and discharge ports are arranged so that the pistons and cylinders will align to draw in liquid on the intake stroke

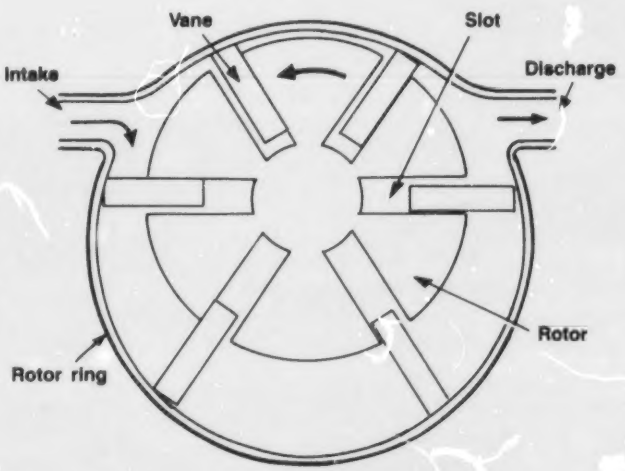

Fig. 7. Vane pump

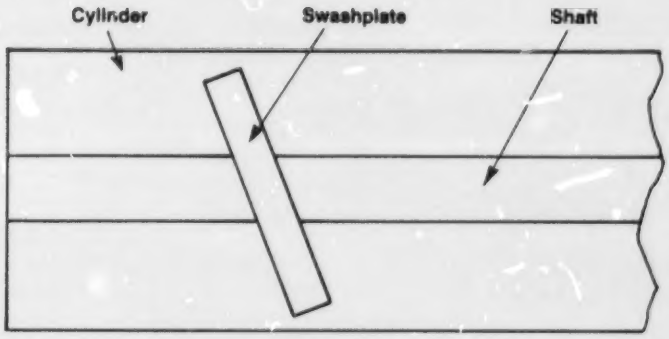

Fig. 8. Simple swashplate

and discharge liquid into the hydraulic system on the discharge stroke. Each piston acts as an independent pump, opening and closing valves and pumping liquid in its own cycle.

A second type of axial piston pump has a *revolving swashplate and a stationary cylinder block* (fig. 10). The pistons and valves operate in this pump exactly as they do in the rotating cylinder block pump. The only difference is that the swashplate rotates, causing the pistons to move back and forth in the cylinders.

A third type, known as a *bent-axis axial piston pump*, has a rotating cylinder block connected to a rotating plate (fig. 11). The cylinder block rotates at an angle to the rotating plate. The two are connected by a shaft and a universal joint. Both the cylinder block and the angled rotating plate are enclosed in the pump housing. This type of pump has ports and valves arranged like those of the pump with the rotating cylinder and stationary swashplate.

Radial piston pumps, as the name implies, have cylinders located around the radius of the pump housing. There are two types of radial piston pumps. One has a rotating cam that actuates the pistons and gives them a reciprocating motion. The other has a stationary shaft and a rotating cylinder to provide the reciprocating action of the pistons.

The *rotating cam radial piston pump* has a stationary cylinder housing (fig. 12). As the cam rotates, the eccentric shape of the cam forces the pistons outward. Since the cam cannot pull the pistons back, springs are used to hold the pistons against the cam. Thus, as the cam recedes while rotating, the springs force the pistons inward. The intake and discharge ports for the liquid are located at the outer end of the pistons. The intake valves are located at the intake port from the reservoir. The discharge valves are located at the discharge port to the hydraulic system.

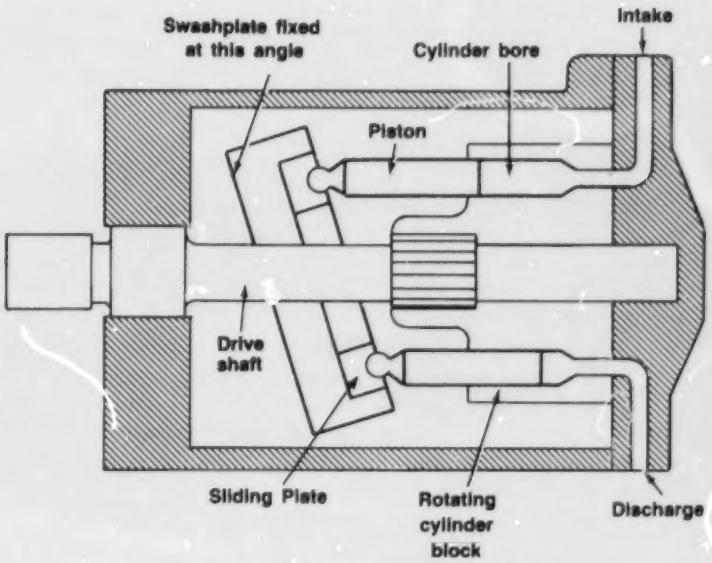

Fig. 9. Rotating cylinder axial piston pump

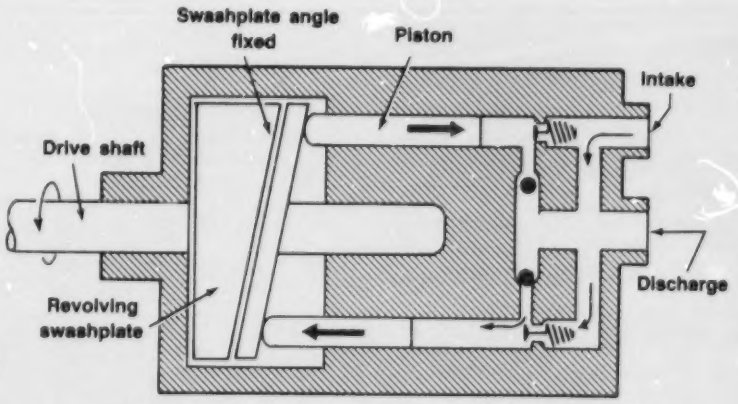

Fig. 10. Revolving swashplate axial piston pump

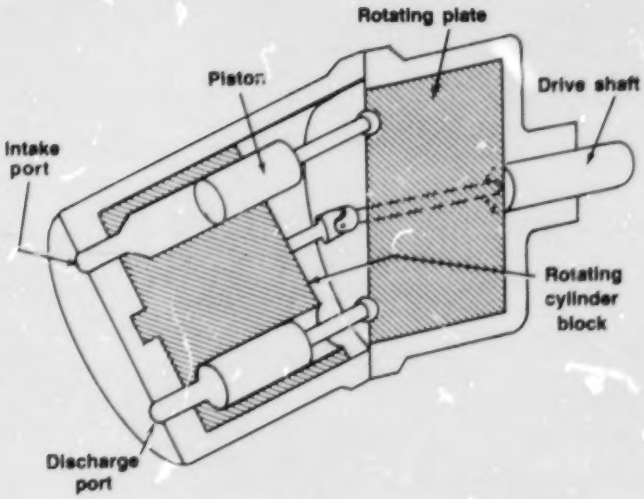

Fig. 11. Bent-axis axial piston pump

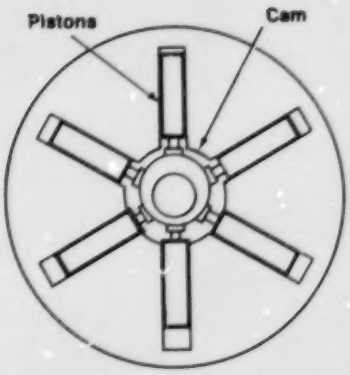

Fig. 12. Rotating cam radial piston pump

In operation, a vacuum is created as the springs force the pistons towards the center. This allows the atmospheric pressure on the liquid to overcome the spring on the intake valve. The valve opens, and liquid is drawn into the cylinder as the pistons recede. When the cam begins to return the pistons on its compression stroke, the vacuum ceases to exist and compression of the liquid begins. The intake valve closes when the vacuum is relieved. At the same time, the compression of the liquid overcomes the spring on the discharge valve, causing it to open. It remains open until the compression stroke is completed. At this time the cycle begins again. Since most pumps have four or eight pistons and cylinders, a fairly constant supply of liquid is pumped throughout a single rotation of the cam.

The *rotating cylinder radial piston pump* is actually called a *rotating piston pump*. In operation, it performs much like the vane pump. The cylinder and its pistons are offset from the center of the housing (fig. 13). As the cylinder rotates, centrifugal force holds the pistons against the inner surface of the housing. At one point, the pistons are pushed in as far as they can go. At 180° from this point, the pistons are forced as far out of the cylinder as they can go. Notice that the intake and discharge ports on this type of pump are located at the center of the rotating cylinder. Thus, as the pistons move out, they create a vacuum that draws the liquid into the cylinder. As the cylinder continues to rotate, the pistons are pushed back into the cylinder, which forces the liquid out the discharge port and into the hydraulic system.

Exercise

1. What is a *pump?*

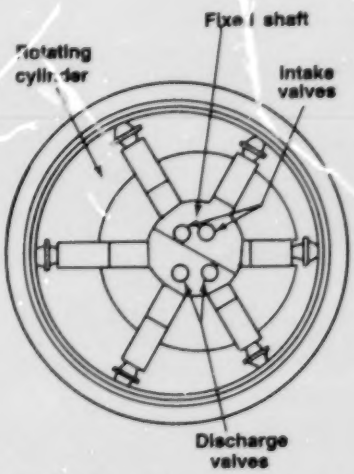

Fig. 13. Rotating cylinder radial piston pump

2. What is the purpose of transferring an external force to a liquid?
3. What are the two classifications of pumps?
4. What happens if the flow of liquid is stopped while a positive-displacement pump continues to operate?
5. What prevents the liquid being pumped by a non-positive-displacement pump from returning to the pump chamber?
6. What does *reciprocating* mean?
7. What prevents the liquid from returning to the reservoir or the pump cylinder in reciprocating pumps?
8. Name five types of rotary pumps.
9. What is *centrifugal force?*
10. In which direction does the liquid flow in a centrifugal pump?
11. Where does the liquid travel through an external gear pump?
12. What is the purpose of the crescent in an internal gear pump?
13. What seals the liquid between the lobes of a rotor pump?
14. How does the number of lobes of the two gears compare?
15. Where is the seal made on vane pumps?
16. What is the purpose of offsetting the rotor in a vane pump?
17. What is used to provide the reciprocating motion of an axial piston pump?
18. In which direction is the swashplate mounted in relation to the cylinders?

19. What are the two methods of developing reciprocating action with a swashplate in axial piston pumps?
20. Why are several cylinders used on axial piston pumps?
21. How does the bent-axis axial piston pump differ from the axial piston pumps with swashplates?
22. What are the two methods of providing reciprocal action to radial piston pumps?
23. Where are the intake and discharge ports of a rotating cam radial pump located?
24. Where are the intake and discharge ports of the rotating cylinder radial pump located?

6

Hydraulic Valves

Objectives: After completing this assignment, you will be able to—
1. explain the functions of the various valves and
2. explain how the various valves operate.

Valves control the functions of a hydraulic system. They control the pressure throughout the system, direct the liquid to the proper circuits, and regulate the volume of liquid to each circuit. Three different types of valves are used to perform these functions: (1) pressure control valves, (2) directional control valves, and (3) volume control valves.

Pressure Control Valves

Pressure control valves limit the pressure in a hydraulic system, unload the excess liquid from the pump when proper pressure for the system has been reached, and regulate the pressure at which liquid enters a circuit.

Relief valves are used to protect the hydraulic system when excessive pressures develop. The sole function of a relief valve is to prevent the hydraulic system from developing pressure above a given amount.

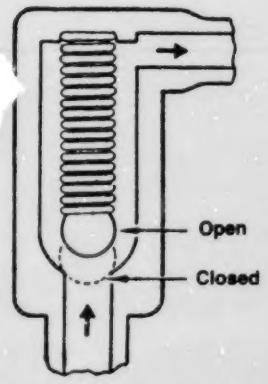

Fig. 1. Spring pressure must be overcome to unseat the ball of a simple relief valve.

A *simple relief valve* (fig. 1) has a valve, a seat, and a spring with calibrated tension. As long as the system pressure is within the safe operating range, the spring tension overcomes the pressure from the hydraulic system and the valve remains closed (fig. 1). However, when the pressure becomes greater than the safe operating range, liquid pressure overcomes the spring tension. This forces the valve open and allows the liquid to return to the resevoir (fig. 1). When the pressure drops again to the safe operating range, the spring tension will overcome the liquid pressure and close the valve again.

Some relief valves are equipped with an adjustment screw (fig. 2). The screw can be screwed down to increase the tension and raise the liquid pressure level required to raise the valve, or it can be loosened to lower the pressure level at which the liquid pressure can raise the valve. While most relief valves use a ball, some are made with valves shaped like buttons, small cones, or disks.

A *pilot-operated relief valve* is used when the valve must handle large volumes and when there must be little difference in pressure between the point at which the valve opens and when it closes. The pilot valve controls the amount of pressure on the backside of a relief valve. When the pilot valve opens, it allows

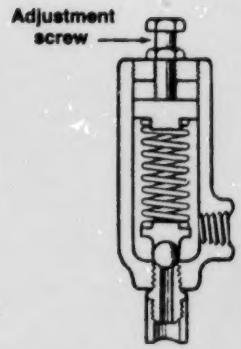

Fig. 2. Relief valve pressure level can be adjusted with the adjustment screw.

the liquid pressure to overcome the spring tension of the relief valve and allows it to open. When the liquid pressure becomes less than that of the pilot setting, the relief valve will close.

Pressure-reducing valves are required when the main circuit delivers high or fluctuating pressures even though a branch of the circuit requires a lower constant pressure. Figure 3 shows a typical reducing valve when the pressure is balanced and the valve is not operating. It is in an open position during this time, and the liquid flows freely. Figure 4 shows how the valve reacts to an increase in pressure. The increased pressure in the secondary circuit is routed to a chamber below the pressure-reducing valve. This causes the valve to lift up, partially closing the port into the secondary circuit. The amount of liquid allowed to pass is

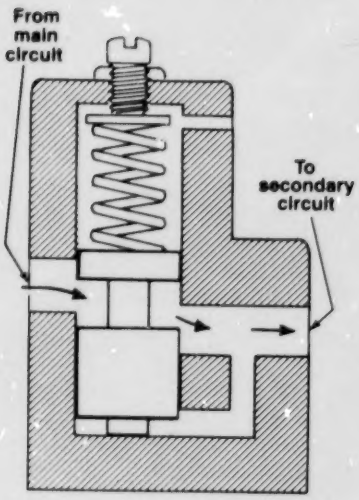

Fig. 3. Pressure-reducing valve does not work when pressure is balanced.

determined by the tension of the spring above the valve. As the pressure in the secondary circuit lowers to the proper level, the valve spring pressure overcomes the resistance by the liquid below the valve and opens it again. This type of valve is called a *constant reduced pressure valve*. Regardless of the amount of pressure in the main circuit, the pressure in the secondary circuit will remain the same. A second type of valve is the *fixed amount reduction valve*, shown in figure 5. This valve operates by maintaining a balance between the pressure of the main circuit and the combined pressures of the valve spring and secondary circuit. Thus, the amount of reduction will always remain the same. However, the pressure in the secondary circuit will fluctuate as the pressure in the main circuit fluctuates. Yet the amount of reduction between the main circuit and the secondary circuit remains constant.

Pressure sequence valves are used to direct liquid from one branch of a circuit to another branch after the needs of the first branch are filled. They operate much like a relief valve. Figure 6 shows a sequence valve closed. At this point, the system is producing only enough liquid for the primary circuit. Figure 7 shows the sequence valve open and supplying liquid to both the primary and secondary circuits. When the pressure in the primary circuit reaches a preset point, the pressure in the circuit forces the valve from its seat, and it remains there as long as the system provides more liquid than that required by the primary circuit.

Unloading valves dump the liquid back into the reservoir at low pressure after the system pressure has been reached. They work much the same as a relief valve but with a different purpose. Many functions of hydraulic systems do not require a constant flow of liquid. During the time it is not needed, the liquid must be pumped back to the reservoir. This could be done by the relief valve. However, this requires the system to develop considerable pressure, which produces a waste of energy. It is better to dump the liquid at a lower pressure. That is the

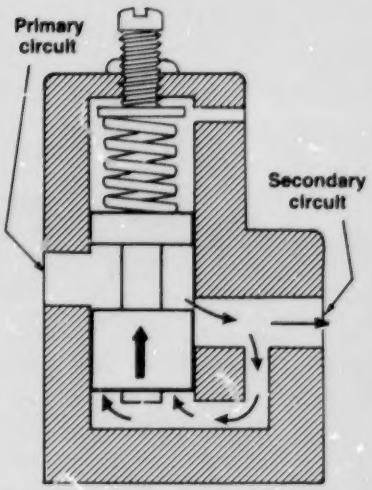

Fig. 4. Increased pressure in secondary circuit lifts piston and reduces size of port.

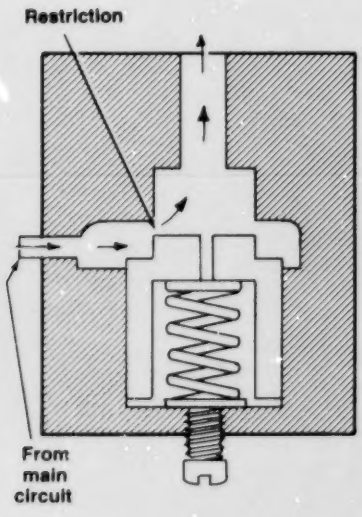

Fig. 5. The secondary circuit pressure is equal to the spring pressure.

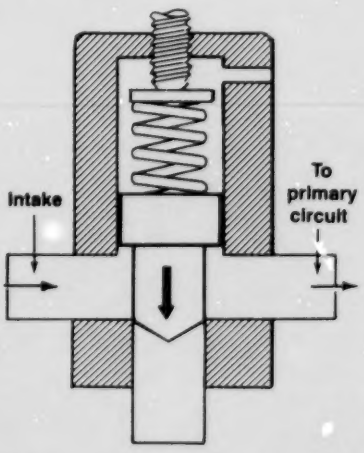

Fig. 6. Valve is closed before system reaches operating pressures.

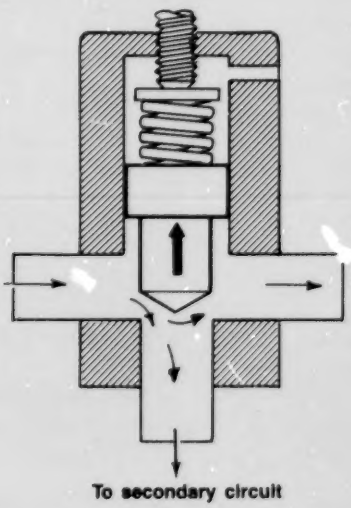

Fig. 7. Valve opens, supplying liquid to secondary circuit, when primary circuit is satisfied.

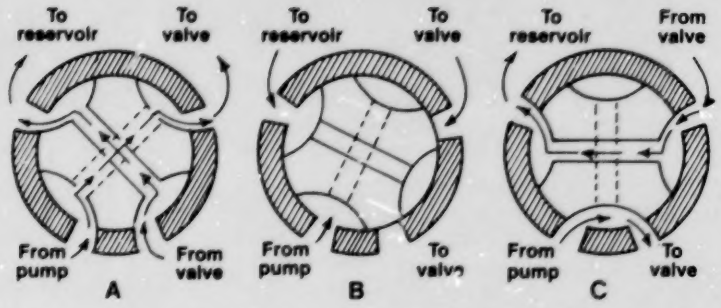

Fig. 8. Rotary valve positioned to do work (A), in the off position (B), and positioned for different systems to work (C)

function of the unloading valve. When the pressure exceeds the needs of the system, the unloading valve opens and returns the liquid to the reservoir.

Directional Control Valves

Three types of control valves are used to direct liquid from one circuit or branch to another. They are check valves, rotary valves, and spool valves.

Check valves are simple one-way valves. They are an application of the valve used as a relief or unloading valve. Liquid flowing in one direction opens the valve and permits the liquid to pass, while liquid flowing in the opposite direction closes the valve and prevents the liquid from passing.

Rotary valves (fig. 8) are cylinders that are machined to fit snugly in a housing. The housing has ports that are connected to the reservoir and to the circuits that perform the work. The cylinder has matching holes that align with those in the housing when turned to the "on" position. The holes in the cylinder do not align in any other position. The cylinder may be turned by a hand lever or hydraulically.

Spool valves are the ones most often used in hydraulic systems to control all phases of the system. Two features of the spool valve make it more desirable than other types of valves. These are its adaptability and compactness. A spool valve can be adapted to fit many different functions by adding lands and ports. (*Lands* are the raised sections on each side of a groove.) It can be operated alone, or multiple spools can be stacked together to serve several functions.

Figure 9 shows a three-position, four-way valve. What this means is that the spool can be positioned in three settings, and the valve has four ports through which the liquid can be directed. You will notice that liquid is allowed to flow back to the reservoir at each end of the spool. This prevents a buildup of pressure on one end that would prevent the spool from moving in either direction. Also, notice that there is always a balanced amount of liquid pressure on each side of a land. This prevents liquid pressure from forcing the spool in one direction because of an unbalanced liquid pressure. As you can see in figure 9, with the spool moved to the lower position, all the ports are open. This permits liquid from the pump to flow through the valve and be directed through the branch of the circuit that forces the piston to the right. At the same time, the liquid in the cylinder on the right side of the piston is allowed to flow back through the spool valve and to the reservoir.

The direction of the piston movement can be reversed by changing the position of the spool, as shown in figure 10. This routes liquid from the pump through the valve and to the branch that supplies liquid to the right side of the piston. This moves the piston to the left, which blocks off the liquid from the left side from the port to the pump and to the port to the right. However, it opens the port to the reservoir and allows the liquid to flow from the left side of the piston back to the reservoir.

All spool valves are either open-center or closed-center valves. An *open-center* valve is shown in figure 11. As you can see, the ports from the pump and to the reservoir are always open during neutral or in a working position. A *closed-center* valve (fig. 12) is one that closes the port from the pump when the valve is in the neutral position.

Volume Control Valves

Volume control valves control the volume or flow of oil by throttling (restricting) the liquid or by diverting part of the flow back to the

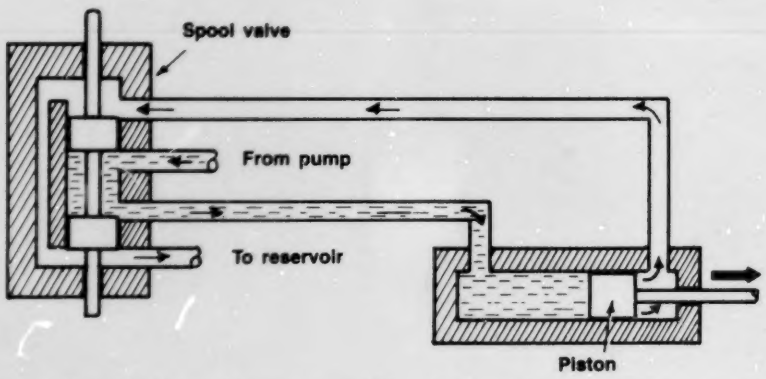

Fig. 9. Liquid is routed to piston on left side. Liquid is routed from piston to reservoir on right side of piston.

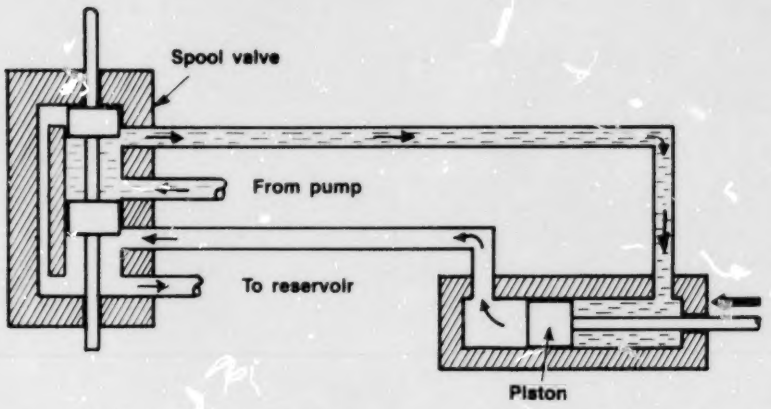

Fig. 10. Liquid is routed to right side of piston. Liquid is routed from left side of piston to reservoir.

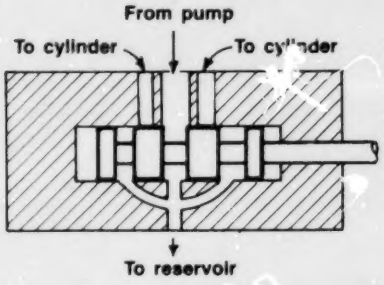

Fig. 11. Open-center valve routes liquid to reservoir in neutral.

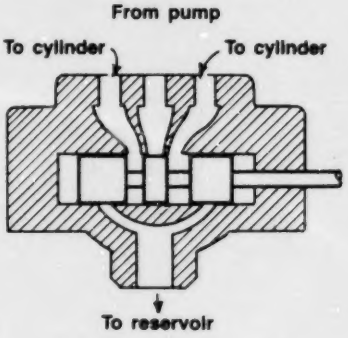

Fig. 12. Closed-center valve blocks liquid from pump during neutral.

liquid supply circuit. This type of valve has a metered orifice in a sliding cylinder. This sliding cylinder covers and uncovers a bypass port as the pressure varies. The position of the cylinder is regulated by spring force on one side of the sliding cylinder and liquid pressure on the other. Liquid that flows through the metered orifice flows to the circuit being supplied while the liquid directed to the bypass port flows back to the reservoir. In figure 13A, you can see how the valve operates. When pressure is not too great, spring pressure holds the sliding cylinder so that it covers most of the bypass port. In this position, most of the liquid flows through the orifice and into the circuit the valve supplies. As the liquid pressure increases, it overcomes the spring pressure and uncovers more of the bypass port (fig. 13B). This relieves pressure on the orifice and drops the flow of liquid back to the preset level.

Proportional flow dividers are valves that separate the flow of a single circuit into two branches. A simple proportional flow divider is shown in figure 14. This valve provides an equal amount of liquid to each branch. You will notice that the face of each side of the valve is the

reservoir. They are usually used in systems in which the speed of the device doing the work is regulated.

Throttling (restricting) the flow to a device that needs to be speed-regulated is done with noncompensating valves. *Noncompensating valves* are those that do not have a mechanism to compensate or allow for pressure changes in the liquid supply circuit. In these instances, a closely regulated liquid flow is not necessary. A needle valve or a globe valve is usually used as a throttling device.

Diverting flow to a device that must be speed-regulated is done with a compensated flow valve. A *compensated flow valve* is one that maintains a constant flow regardless of changes in the volume of the

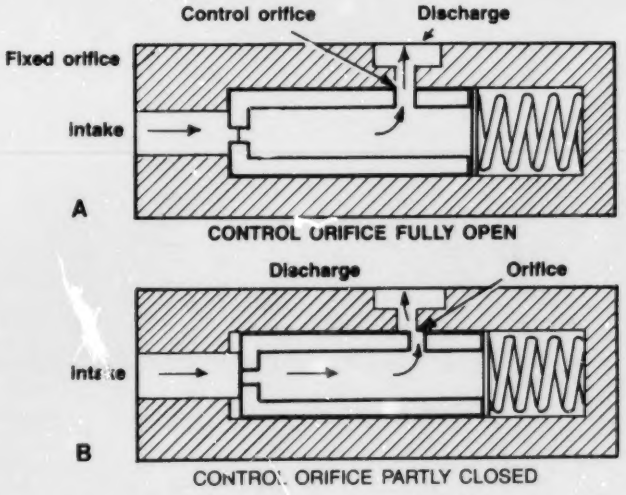

Fig. 13. **A:** *Balanced pressure;* **B:** *Liquid pressure on cylinder overcomes spring pressure and reduces size of orifice opening.*

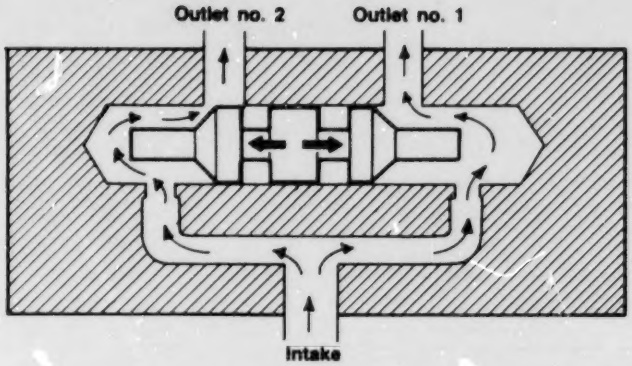

Fig. 14. Free floating valve balances secondary branch pressures according to face size on each side of the valve.

same size. This means that an equal pressure will exist on each side. In operation, the needs for liquid in each of the branches will vary. When the need increases on one side, the pressure on that side will drop. This creates an unequal balance on the free floating valve. The valve moves in the direction of the lesser pressure. As it moves, it uncovers the port on the low pressure side. This creates a balanced pressure, and the valve will move to uncover both ports as the needs of the two branches are met. If one branch of a system requires more liquid than the other, a proportional valve of the correct proportion can be selected. The ratios can range from 50:50 to 90:10. The proportion will be reflected in the respective face sizes of the floating valve.

Miscellaneous valves such as cock valves, gate valves, globe valves,

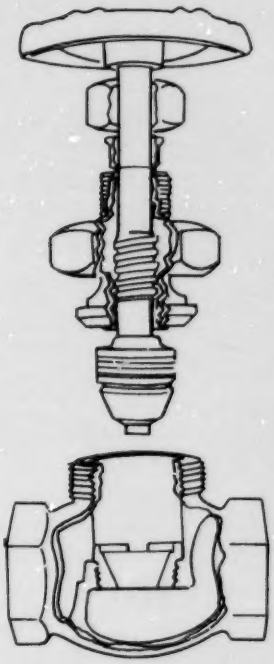

Fig. 17. Exploded view of a globe valve

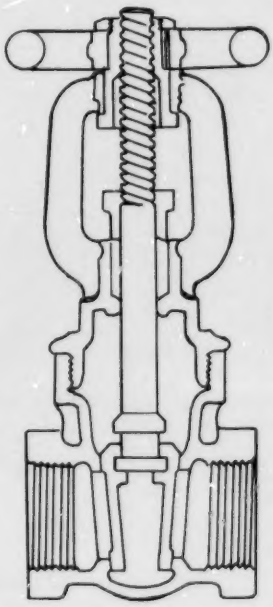

Fig. 16. Gate valve

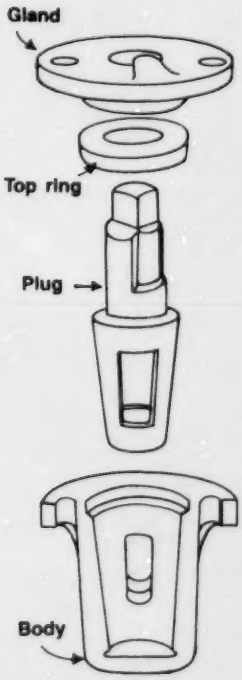

Fig. 15. Parts of a cock valve

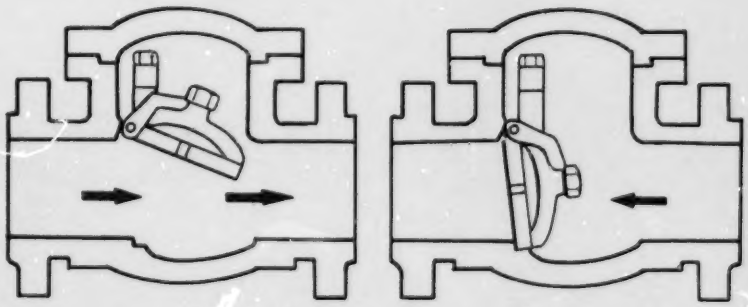

Fig. 18. Flapper valve permits flow in one direction only.

and flapper valves are commonly used in hydraulic systems.

A *cock valve* is one that is permanently seated in the pipe and serves the sole function of turning the liquid supply on and off (fig. 15).

A *gate valve* is a wedge-shaped gate that stands above the line of flow (fig. 16). It is connected to a handle by a screw that lowers the valve to stop the flow of liquid. The wedge is forced down between valve seats that mate with the wedge.

A *globe valve* is similar to a gate valve, but it uses a sharply tapered plug, ball, or disk that fits snugly in the seat to cut off the supply of liquid (fig. 17).

A *flapper valve* is a directional valve that permits liquid to flow in one direction only. Its operation is shown in figure 18.

Exercise

1. What functions do valves serve in a hydraulic system?
2. What functions do pressure control valves serve?
3. What is the sole function of a relief valve?
4. What are the parts of a simple relief valve?
5. What may be used in place of a ball in a relief valve?
6. What is the purpose of a pilot-operated relief valve?
7. When are pressure-reducing valves used?
8. What are two types of pressure-reducing valves?
9. What are pressure sequence valves used for?
10. What is the purpose of an unloading valve?
11. Unloading valves work much the same as what other valve?
12. What is the function of check valves?
13. How does a rotary valve work?
14. What features of the spool valve make it desirable?
15. How is a spool valve adapted for special functions?
16. Why is liquid allowed to return to the reservoir regardless of the position of the spool?
17. Why must there always be a balanced amount of liquid on each side of the spool?
18. What are the two kinds of spool valves?
19. What happens to the liquid when it reaches the open-center valve in neutral?
20. What kind of valve would work with a closed-center spool valve to prevent damage to the system?
21. How do volume control valves work?
22. What does a compensated flow valve compensate for?
23. What is the working part of a compensated flow valve, such as shown in figure 13?
24. What is the purpose of proportional flow dividers?
25. What determines the proportion of the liquid that flows to each of the branches?
26. What is the function of a cock valve?
27. What moves the gate of a gate valve to the open and closed positions?
28. What part of a globe valve fits in the seat to cut off liquid?
29. What is the purpose of a flapper valve?

7

Hydraulic Cylinders

Objectives: After completing this assignment, you will be able to—
1. explain the types of cylinders;
2. explain how each of the cylinders operates; and
3. explain the purpose of the parts of the cylinders.

Cylinders are among the devices used to convert hydraulic or liquid power back into mechanical energy. Two types of cylinders are used for this purpose—the piston cylinder and the vane cylinder. The piston cylinder gives a straight back-and-forth movement, while the vane cylinder gives a rotary back-and-forth movement.

Piston Cylinders

The two types of piston cylinders are the single-acting cylinder and the double-acting cylinder.

The *single-acting cylinder* has a single port that is used both to allow liquid to enter the cylinder and to discharge it from the cylinder. Obviously, liquid is admitted to only one side of the piston (fig. 1). This means that liquid pressure is exerted in only one direction. The return of the piston to its original position is done either with a return spring or by gravity.

Piston seals are located around the circumference of the piston to prevent liquid from leaking from the liquid compartment side of the cylinder. It also prevents air from leaking into the hydraulic system.

On the opposite side of the piston is an air chamber. An air vent in the cylinder is provided to prevent a buildup of air or the creation of a vacuum. Either condition would affect the efficiency and operation of the cylinder.

The *double-acting cylinder* (fig. 2) has two ports through which liquid is supplied to the cylinder and from which the liquid is discharged from the cylinder. Liquid is forced into one side of the cylinder to extend the piston. As the piston moves out, the liquid on the opposite side of the piston flows back to the reservoir. The piston is moved in the opposite direction by admitting liquid to the opposite side and reversing the process.

Since liquid pressure is exerted in the compartment through which the piston rod operates, a second seal is required to prevent the liquid from leaking out around the piston rod.

Automatic stops limit the piston travel. These stops are adjustable so that the cylinder moves to the correct length each time. Figure 3 shows how the control mechanism works. A stop valve is inserted in the cylinder housing between the liquid port and the outlet connection. A rod extends parallel to the piston to a point where the piston rod stop can contact it. The piston rod stop is adjusted so that as the piston approaches the desired extension, the stop moves the stop valve to close

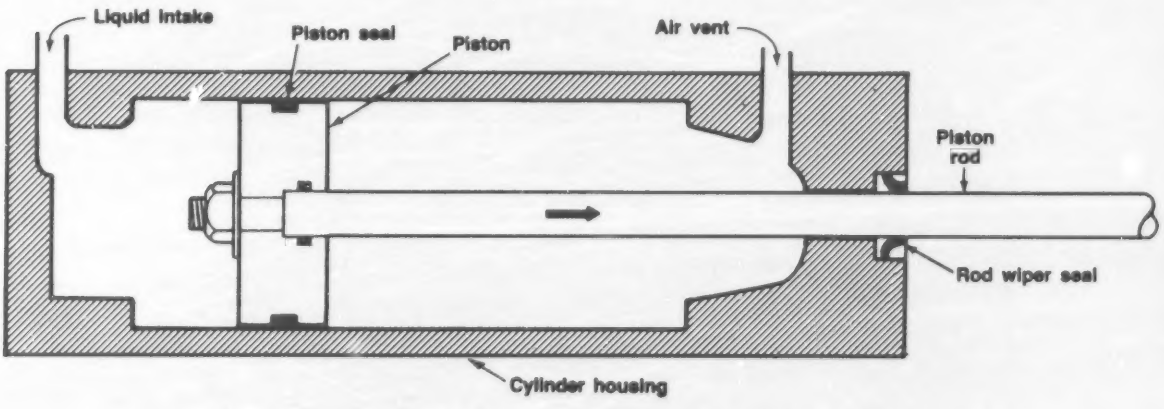

Fig. 1. Single-acting cylinder exerts hydraulic pressure in one direction only.

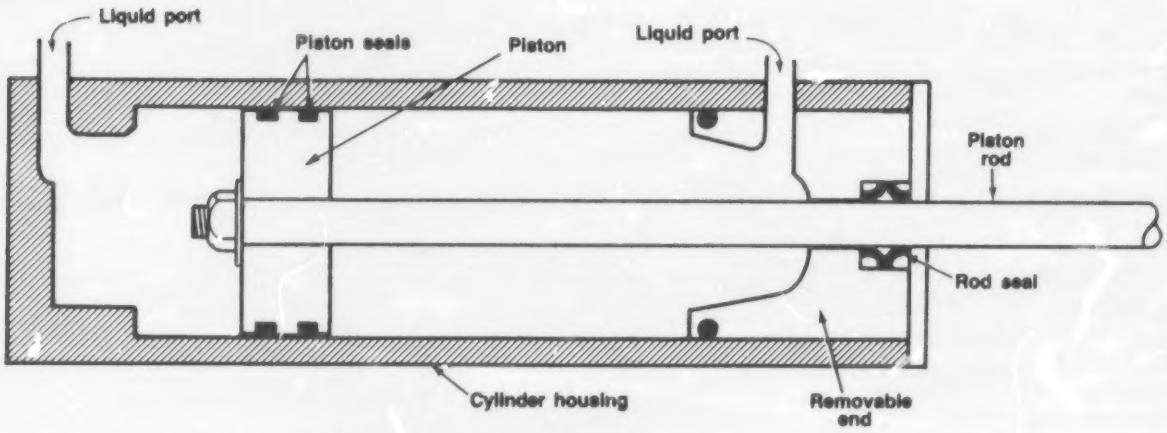

Fig. 2. Double-acting cylinder exerts hydraulic pressure in both directions.

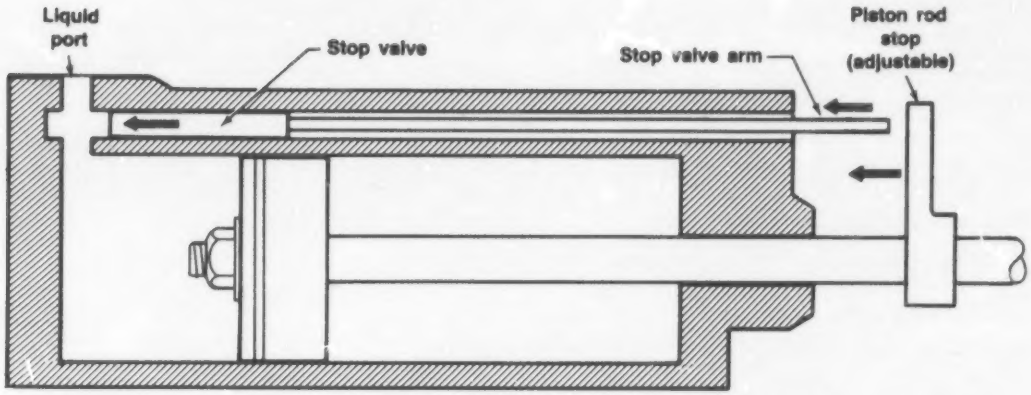

Fig. 3. Hydraulic pressure stops piston movement when stop valve seats in liquid port.

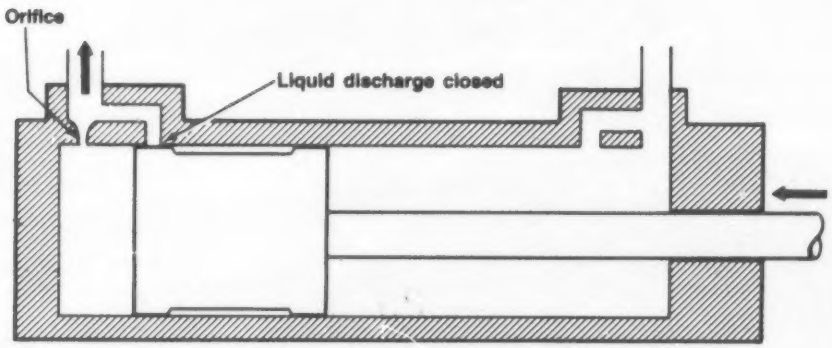

Fig. 4. Closed port slows piston by reducing liquid flow.

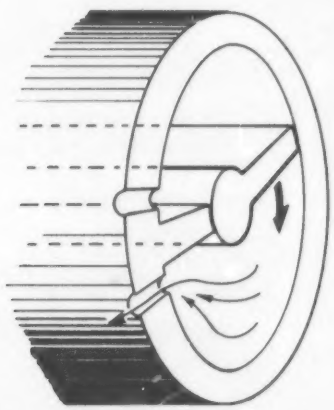

Fig. 5. Vane cylinders produce rotary movement.

the discharge port. This traps the remaining liquid in the cylinder, which, since the liquid is incompressible, stops the piston.

A *fluid cushion* is sometimes used in some cylinders to protect them from the impact of sudden stops. This cushion is a method of slowing the piston before it reaches the end of its stroke. This is done by using two small discharge ports rather than one larger one. One port is closer to the end of the cylinder than the other (fig. 4). As the piston approaches the end of the stroke, it covers the first of the two ports. This reduces the flow of liquid from the cylinder. The piston is slowed by the reduction in liquid flow. As the piston covers the second port, the trapped liquid in the end of the cylinder stops the piston movement.

Vane Cylinders

Vane cylinders do not have the straight back-and-forth motion of piston cylinders. Rather, the shaft in the cylinder rotates from side to side. The vane cylinder (fig. 5) has a fixed vane on the cylinder wall. Its outer edge forms a seal with the rotating shaft. A second vane is attached to the shaft. This vane forms a seal with the inside cylinder surface. This divides the interior of the cylinder into two compartments. A port on each side of the fixed vane admits and discharges liquid. A second port can be used in the same manner as the ones in the piston cylinder to prevent damage from the impact of sudden stops.

In operation, an arm is attached to the protruding end of the shaft. This arm is attached to the device that does the work. Being a double-acting cylinder, liquid flows out of the one side of the cylinder as other liquid is forced into the other side. This rotates the shaft and arm. The procedure is reversed to cause the arm to rotate in the opposite direction.

Exercise

1. What is the function of cylinders?
2. What two kinds of movement can cylinders provide?
3. What returns the piston to the original position in a single-acting cylinder?
4. Why is an air chamber required in single-acting cylinders?
5. How does the operation of a double-acting cylinder differ from that of a single-acting cylinder?
6. What is the function of an automatic stop?
7. How does the automatic stop limit piston travel?
8. What is the purpose of a fluid cushion?
9. What is used to slow the piston before it reaches the end of its stroke?
10. How do the two ports work to slow the piston?
11. Where are the two vanes of the vane cylinder attached?
12. Why are two vanes used?
13. Where do the two vanes form a seal?

8

Hydraulic Motors

Objectives: After completing this assignment, you will be able to—
1. name the moving parts of the various hydraulic motors and
2. explain how each of the hydraulic motors operates.

Hydraulic pumps convert mechanical energy into hydraulic energy. Hydraulic motors convert hydraulic energy into mechanical energy. It is not surprising then to find that hydraulic motors are very similar to hydraulic pumps. The major difference between the two is that a pump drives its liquid while a motor *is driven by* its liquid. The very principles that make a pump work also make a motor work. Just as there are gear pumps, vane pumps, and piston pumps, so there are gear motors, vane motors, and piston motors. It is not uncommon to see a gear pump connected to a similar looking gear motor through a hydraulic system.

Gear Motors

As with gear pumps, there are two types of gear motors—the external gear motor and the internal gear motor.

External gear motors (fig. 1) have two gears, which are the same size. The teeth of the gears form a seal at the inside wall of the motor housing and at the point at which the two gears mesh. This separates the intake chamber from the discharge chamber.

Figure 1 shows the operation of the external gear motor. As liquid is pumped into the inlet of the motor under pressure, the teeth of the motor are forced to rotate away from the intake port. The shaft to one of the gears is a drive shaft. As the gears rotate, the drive shaft rotates, powering the machinery attached to it. The meshing teeth of the gears force the liquid into the compartment near the discharge port. This port carries the liquid back to the reservoir at low pressure. It is the difference between the high pressure entering on the intake side and the low pressure on the discharge side that provides the torque for the motor.

Internal gear motors (fig. 2) have two gears also. However, one of the two gears is internal, meaning the teeth face the inside. The teeth of the external gear mesh with the teeth of the internal gear. A crescent is placed inside the internal gear that meshes with the internal gear teeth on one side and the external gear teeth on the other. This divides the interior of the motor into two chambers. The intake port is in one chamber, and the discharge port is in the other.

In operation, the internal gear motor operates much the same as the external gear motor. Liquid is forced into the intake chamber and causes the gears to rotate towards the discharge chamber. The meshing teeth cause the liquid to be forced

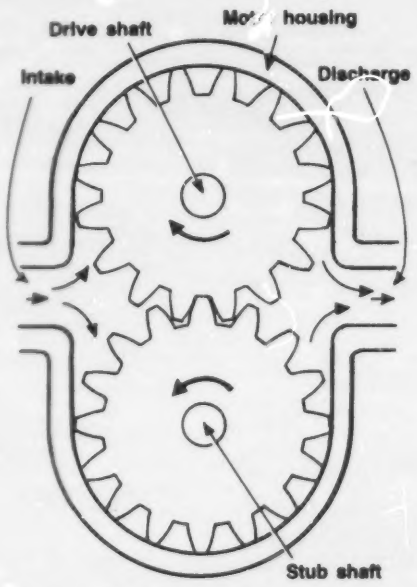

Fig. 1. Gear teeth form a seal with housing and at the point where they mesh.

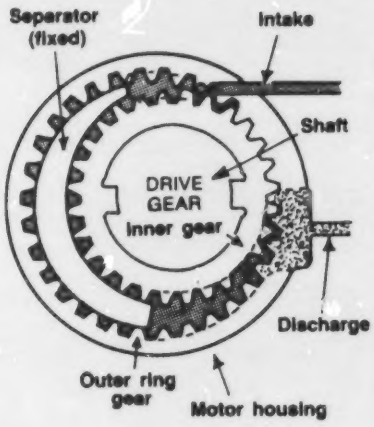

Fig. 2. Crescent forms seal with both gears.

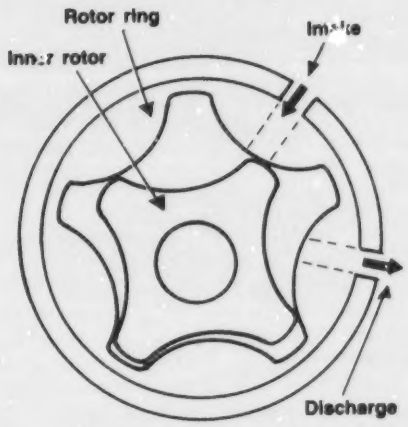

Fig. 3. The lobes of the external gear slide along the surface of the internal gear to form a seal.

out the discharge port at low pressure. The external gear is mounted on a splined output shaft. This shaft provides torque to the machinery attached to it.

The rotor-type internal gear motor (fig. 3) is a variation of the internal gear. Actually, the parts are not gears at all, but a rotor and a rotor ring. The rotor ring has one more lobe than the rotor. The lobes are designed so that only one lobe of the rotor is in mesh with the rotor ring at one time. The other lobes slide along the outer surface of the rotor ring, forming a seal and moving one lobe past its starting point on each revolution. As the lobe comes back into mesh with the rotor ring, it forces the liquid out through the discharge port which is located at this point. Thus, liquid is forced into the intake side under pressure, rotates the rotor and rotor ring, and is discharged on the discharge side under low pressure.

Vane Motors

Vane motors (fig. 4) operate much like rotor motors. Vanes fit in slots in the rotor, which is offset. Ths housing surrounding the rotor is circular. Centrifugal force holds the vanes in contact with the housing. On the intake side of the chamber, liquid under pressure is forced into the chamber. It is held in the space between the vanes. Since there is more volume on the side with the extended vanes, there is also more pressure. This causes the rotor to rotate in that direction. As the vanes begin to move back in towards the rotor, liquid is forced through the discharge port at low pressure.

Piston Motors

Axial piston motors are those in which the cylinders and pistons operate parallel to the axis of the motor (fig. 5). The pistons move back and forth to provide torque. The back-and-forth movement of the pistons is converted to torque (twisting motion) by a swashplate. A *swashplate* is a plate that is tilted at an angle from a right angle to the cylinder bore. The swashplate is mounted in a fixed position. Notice that the pistons are connected directly to the swashplate. The swashplate rotates on the face of a swashplate yoke. The back-and-forth action of the pistons comes from rotating the cylinder block. This also rotates the pistons.

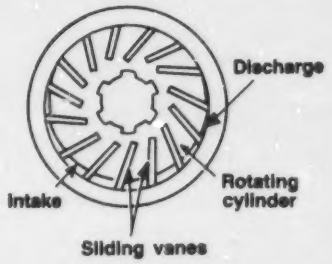

Fig. 4. Liquid is carried in the space between the vanes.

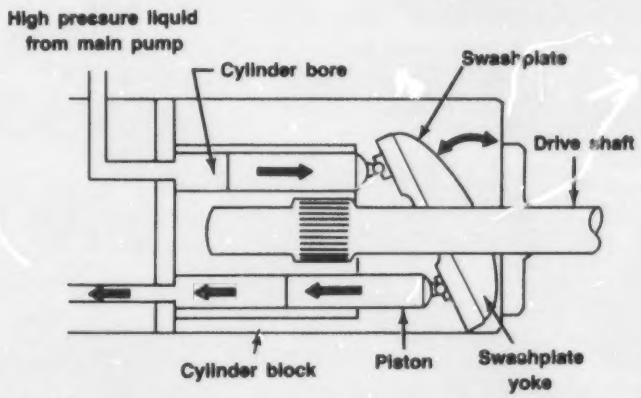

Fig. 5. Reciprocating action is converted to rotary motion by the swashplate.

As they rotate, they follow the fixed angle of the swashplate. The cylinder block is mounted to the drive shaft.

In operation, liquid starts being forced into the cylinder while the piston is at the top of its stroke. This causes the piston to slide down the swashplate. In order to slide down the swashplate, the cylinder must rotate. A second piston reaches the top of its stroke and goes through the same process. This rotates the cylinder even further. This procedure is repeated until all the pistons have been activated. When the piston reaches the bottom of its stroke, the discharge port allows the liquid to flow back to the reservoir under low pressure. Each cylinder will discharge its liquid and return to the top of its stroke in its own time. Then the procedure will be repeated.

Radial piston motors have cylinders located around the radius of the motor housing (fig. 6). The cylinder and pistons are located in an eccentric position. That is, the cylinder is offset from the center of the motor casing. This means that the pistons must move in and out of the cylinders in order to remain in contact with the casing as the cylinder turns.

In operation, liquid is forced into the cylinder under pressure. This develops an outward pushing force on the piston. Since the cylinder is offset, the pressure causes the piston to slide along the surface of the casing. This develops a rotating motion in the cylinder. There may be as many as ten cylinders, each performing the same functions as they rotate just past the closest point in the circle. As the pistons reach the end of their stroke, liquid is allowed to flow through a discharge port at low pressure back to the reservoir. After all the liquid has been discharged, liquid will again be forced into the cylinder, and the cycle will be repeated.

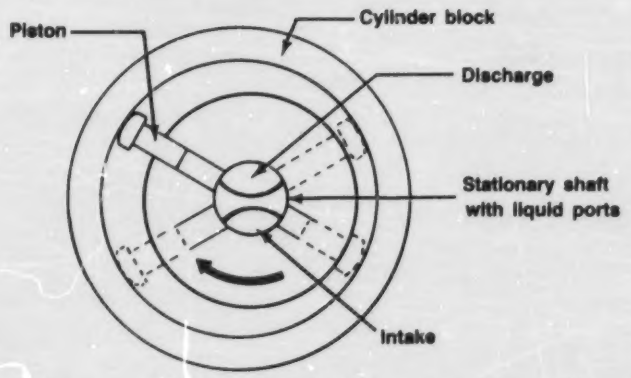

Fig. 6. The movement of a single piston as it rotates one full circle

Exercise

1. What is the major difference between hydraulic pumps and hydraulic motors?
2. Where do the two gears of a gear motor form a seal?
3. Why is it important that the gears form the seal at the two locations?
4. What determines the amount of torque produced by a hydraulic motor?
5. What divides the internal gear motor into two chambers?
6. Which gear is connected to the drive shaft of an internal gear motor?
7. What are the moving parts of a rotor-type internal gear motor?
8. How is the seal made between the intake and discharge compartments of a rotor motor?
9. What causes the vane motor rotor to rotate in the direction it does?
10. What converts the back-and-forth action of the pistons to twisting motion in an axial piston motor?
11. What are the pistons connected to in an axial piston motor?
12. What causes the cylinder to rotate when liquid is forced into the cylinder of an axial piston motor?
13. Where is the cylinder of a radial piston motor located in relation to the motor casing (housing)?
14. What causes the rotating motion in a radial piston motor?

9

Hydraulic Accumulators

Objectives: After completing this assignment, you will be able to—
1. explain the functions of accumulators and
2. explain how the different types of accumulators work.

Functions of Accumulators

An *accumulator* is a device that serves three functions. It absorbs shock, stores energy, and maintains a constant pressure. While each and every accumulator serves all three functions, most are designed to serve only one of these functions. Depending on its use, a hydraulic system will usually have a need for only one of the functions.

Hydraulic liquid is not compressible. For this reason, when its flow is suddenly cut off, there is an instant when the momentum of the liquid continues even though there is no place for the liquid to go. This causes tremendous pressures to develop in the system. As a result, the hydraulic lines expand to accommodate the liquid. It contracts and returns to its original shape when the pressure stabilizes. Although the shock lasts for only part of a second, it creates a strain on the hydraulic system that will cause it to fail in time. Accumulators allow the liquid to flow into them as the resistance builds. This *softens the shock* of sudden pressure surges and allows the liquid to return to the system when pressures have dropped.

Accumulators *store energy* by storing liquid while the system is operating at high pressures and releasing it when the liquid pressure drops during peak periods of use. Thus, the accumulator smooths out the liquid flow between the slack times, when pressure and liquid are plentiful, and those periods of heavy use, when it feeds it back into the system.

Accumulators can be designed to *maintain a constant pressure*. These are large accumulators that are weight-loaded. The constant weight provides constant pressure in the system regardless of changes in the volume of liquid pumped or leaks in the system.

Types of Accumulators

An accumulator is a container that permits liquid to flow into it under pressure. The amount of liquid and the pressure under which the liquid is permitted to flow into it are designed into the accumulator to fit the system it serves. Three types of accumulators may be used.

The **weight-loaded accumulator** (fig. 1) uses a piston, weights, and gravity to provide the correct amount of resistance to the flow of liquid into and out of the accumulator. In operation, liquid flows through the hydraulic system until the pressure builds up to equal that of the weight. At this point, the accumulator will receive the excess liquid at a constant pressure equal to the weight on the acumulator. When liquid pressure drops below that of the weight, liquid flows from the accumulator back into the hydraulic system.

Spring-loaded accumulators differ from weight-loaded accumulators mainly in the change from a weight load to a spring load. Resistance to liquid pressure is provided by a spring, which can be internal or external. Figure 2 shows a typical *internal* spring-loaded accumulator. The spring is calibrated. This means that the spring has been designed to exert a given amount of resistance to being compressed. When liquid pressure begins to exceed the spring

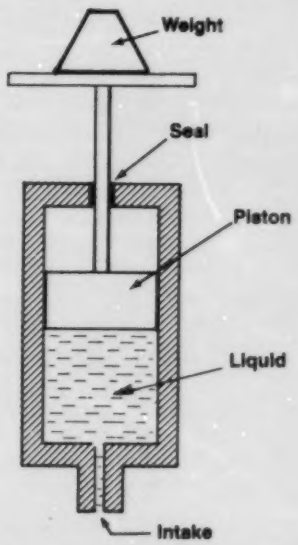

Fig. 1. Parts of a weight-loaded accumulator

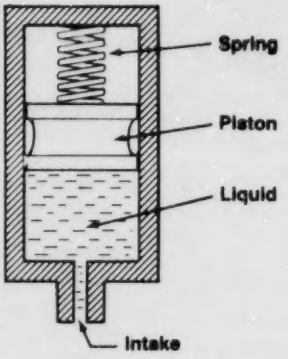

Fig. 2. A spring provides the resistance on this accumulator.

resistance, liquid flows into the accumulator. When the liquid pressure drops, the liquid is forced back into the hydraulic system. This type of accumulator is used to supply liquid pressure when a device is first activated by the hydraulic system. This causes liquid pressure to drop. The accumulator forces liquid back into the system to prevent the pressure from dropping dangerously low. As the accumulator empties its contents, the hydraulic pump begins to develop the pressure back to the operating level. This provides a smooth engagement of the device being activated.

Gas-loaded accumulators (called **pneumatic accumulators**) may use pistons, bladders, or diaphragms to separate the liquid from the gas. Gas is used rather than weights or springs to provide resistance to the liquid pressure. The amount of resistance is varied by increasing or decreasing the amount of gas in the gas chamber. A piston, bladder, or diaphragm is required to separate the gas from the liquid because otherwise the liquid would absorb the gas in time. Piston-type accumulators use an inert dry gas, such as nitrogen, while bladder- and diaphragm-type accumulators use compressed air in the gas chamber.

Figure 3 shows a typical *piston-type* accumulator. Notice that the piston is a free-floating piston that floats on the liquid it separates from the gas. All gas accumulators are equipped with a valve to charge the gas compartment.

Figure 4 shows a typical *bladder-type* accumulator. The bladder is molded to the accumulator at the top of the gas chamber. As with the piston-type accumulator, a gas charging valve is located at the top of the gas chamber. Notice that a protective button is attached to the bottom of the bladder. This prevents the bladder from being forced through the liquid inlet during low-pressure periods, when the bladder expands. This limits the expansion to the interior of the accumulator.

Diaphragm-type accumulators are similar to bladder-type accumulators. However, a metal element is used to separate the gas from the liquid. Expansion is provided by a rubber diaphragm molded to the metal element.

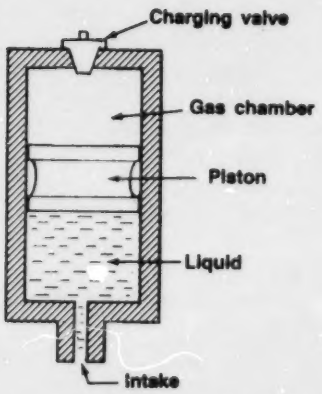

Fig. 3. Gas pressure above the piston determines the amount of resistance to liquid pressure.

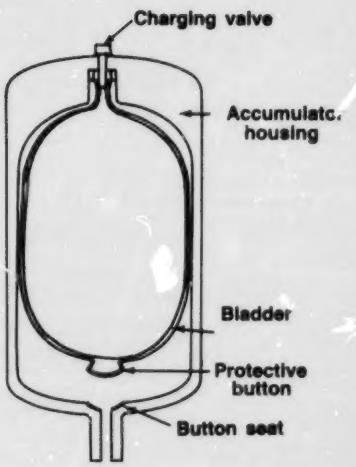

Fig. 4. Parts of a bladder-type pneumatic accumulator

Exercise

1. What three functions do accumulators serve?
2. What causes shock to develop in a system without an accumulator when the flow is suddenly cut off?
3. Why is an accumulator required on a hydraulic system?
4. How does an accumulator relieve shock?
5. How do accumulators store energy?
6. What is a brief description of an accumulator?
7. At what point does liquid flow into a weight-loaded accumulator?
8. What is the maximum pressure permitted by a weight-loaded accumulator?
9. How does a spring-loaded accumulator differ from a weight-loaded one?
10. At what point does liquid flow into a spring-loaded accumulator?
11. How does a spring-loaded accumulator help make a smooth engagement of a device that is activated by the hydraulic system?
12. Name three types of pneumatic accumulators.
13. What determines the amount of resistance provided in a pneumatic accumulator?
14. Why is a piston, bladder, or diaphragm required to separate the gas from the liquid?
15. What kind of gas is used?
16. Why is a bladder equipped with a protective button?
17. How does a diaphragm-type accumulator differ from a bladder-type accumulator?

10

Hydraulic Liquids

Objectives: After completing this assignment, you will be able to—
1. explain why the viscosity of the fluid is important;
2. explain what the Viscosity Index rating means;
3. explain how moisture in the system affects the liquid; and
4. explain how air in the system affects the liquid.

Hydraulic liquids are used to transmit power from one point to another. As was pointed out earlier, liquids serve this function very well because they are not compressible. However, several other factors affect the ability of a liquid to do work efficiently.

One of the more important functions of a hydraulic system is to *lubricate the moving parts*. Different liquids, including hydraulic liquids, have varying abilities to lubricate. Lubrication is accomplished by spreading a coat of liquid over the surface between moving parts that contact each other. If a thin coat of liquid remains while the parts slide or move against one another, the parts are lubricated. However, if the liquid does not have the film strength to resist being wiped or squeezed out from between the surfaces when spread out in a thin layer, the parts are not lubricated. A good liquid will lubricate the moving parts under a wide range of temperatures and under severe weather conditions.

Some liquids are thinner than others and, therefore, flow better. However, if a liquid becomes too thin, it loses its ability to lubricate and to form seals and is more prone to leak. On the other hand, if a liquid is too thick, it resists flow, cannot get in between the close tolerance parts, and causes power loss and higher operating temperatures. Either of these last two conditions will lead to excessive wear and rapid failure. A good liquid must have enough "body" to give a good seal at the pumps, valves, and pistons, but must not be so thick that it offers too much resistance to flow.

The ability of a liquid to flow is affected by temperature. The higher the temperature, the thinner the liquid is and the faster it will flow. The ability of a liquid to flow is measured by its *viscosity*. The viscosity of a liquid decreases as the temperature increases. However, all liquids do not increase or decrease at the same rate. The variation is greater for some liquids than for others. The most common method of determining viscosity is by use of the Saybolt Universal Viscometer. This instrument measures the number of seconds it takes for a fixed quantity of liquid (60 cubic centimeters) to flow through a small orifice of a standard length and diameter at a specified temperature.

Liquids are rated with a *Viscosity Index* (VI). The Viscosity Index is related to the temperatures at which a liquid changes thickness. The lower the VI, the greater are the differences in the thickness at low temperatures and the thinness at high temperatures. Obviously, a higher VI rating is more desirable than a lower rating. A higher rating means that the liquid has less change in thickness at wide temperature ranges. A good hydraulic liquid will be capable of lubricating moving parts with extremely close tolerances. This means the liquid must be thin enough to get into all the tiny spaces and also be thick enough to remain on the parts to provide adequate lubrication, often at high temperatures.

Good hydraulic liquids resist oxidation, rust, corrosion, and foaming. All of these conditions are caused by the absorption of air or moisture by the liquid.

Oxidation of hydraulic liquids produces organic acids. These acids eat at the metal parts of the hydraulic system. They also produce sludges in the system, particularly in the reservoir. These sludges are thick and acidic. In addition to clogging the strainer at the pump, the sludges damage the metal parts.

If more air enters the liquid than it can absorb, bubbles will be formed. As the bubbles are pumped throughout the system under pressure, the churning and swirling of the liquid will cause the bubbles to develop into a foam. While the liquid is not compressible, the air in it is. The foam causes the operation of the hydraulic system to be mushy and difficult to perform correctly. It also reduces the ability of the liquid to lubricate.

Water absorbed into the liquid also causes acids, sludges, rust, and oxidation. The liquid and water combine to form an emulsion. Thus, the liquid itself will carry the moisture throughout the hydraulic system. Of course, moisture will cause rust and oxidation to all metal parts of the system.

Most hydraulic liquids contain ad-

ditives that help the liquid resist absorption of air and water. The additives also help dissolve air bubbles.

As you can see, it is extremely important that the liquid be kept clean. This means that the liquid must be stored in a clean location in clean containers. These containers must be kept closed at all times to prevent contamination. A clean opener and funnel should be used to pour liquid into the system. Use a clean cloth when checking the liquid with a dipstick.

The hydraulic system itself should also be kept clean. This means that dirt and grease should be wiped from filler caps or dipsticks. Steam-clean or use solvents to clean the machine before removing any part from the hydraulic system. Plug or cover any disconnected lines while working on the machine.

Exercise

1. What gives hydraulic liquids the ability to transmit power from one point to another?
2. What can cause a liquid to not lubricate parts of a system?
3. What are the conditions under which a good liquid will lubricate?
4. What happens to a liquid when it becomes too thin?
5. What happens to a liquid when it becomes too thick?
6. How does increased temperature affect a liquid?
7. What is the most common method of measuring viscosity?
8. What does a low VI rating indicate?
9. What conditions are caused by the liquid absorbing air and moisture?
10. What does oxidation produce?
11. What do the acids produce?
12. What causes foam?
13. How does foam in the system affect its operation?
14. What conditions are caused by water being absorbed by the liquid?
15. What is done to help the liquid resist absorbing air and moisture?
16. What should be done to keep the liquid clean?
17. What should be done to keep the system clean?